METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

Readers are invited to submit articles for publication in the editorial pages; photographs and/or drawings suitable for reproduction are especially welcome. Contributions are paid for at the usual rates. We accept no responsibility in connection with submitted manuscript. All editorial communications should be addressed to The Editor, "Metallurgia," 31, King Street West, Manchester, 3.

PRINCIPAL CONTENTS IN THIS ISSUE:

The articles in this Journal are indexed in *The Industrial Arts Index*

Subscription Rates throughout the World - - 24/- per annum, Post free

Published monthly by THE KENNEDY PRESS, LIMITED.

Registered Office: 31, King St. West, Manchester, 3. *Telephone:* BLA 2084. *Telegrams:* "Kenpred," Manchester.
LONDON OFFICE: 21, Bedford Street, W.C.2. *Telephone:* Temple Bar 2629.

METALLURGIA

THE BRITISH JOURNAL OF METALS

INCORPORATING THE "METALLURGICAL ENGINEER."

OCTOBER, 1950 Vol. XLII No. 252

Research Work and Practice

IT is now more fully recognised that in executing its functions of dealing with fundamental problems, the primary concern of a research department is the observation, study and development of scientific advancement with a view to its rapid industrial application. In addition to pioneer work of this kind, the important function of serving the immediate needs of the design and manufacturing departments must not be overlooked. When the research work is undertaken by an industrial firm the choice of problems and the application of the results present no real difficulty, since they are regarded, as a general rule, as the normal step by step advances of the particular works concerned, in producing a new or improved product. On the other hand, the work may have been concerned with methods for ensuring more economical production while maintaining the high quality of the product, and, because of their direct bearing on the successful operations of the works, the cost of applying the results of research are more readily assessed than when the research is carried out by an external organisation.

Many of these research work factors, which influence the choice of problem and the application of results in industry, are referred to in the Report of the Department of Scientific and Industrial Research* recently published, although it is mainly concerned with brief reviews of the work of the Department's own Research Establishments and of the Industrial Research Associations. Choice of problems, in the case of the Establishments, is made primarily on the advice of their respective Boards and two difficulties are encountered which are causing some concern. The first is the difficulty of keeping programmes within such limits as will ensure an adequate effort being devoted to each problem that is accepted and the second is the need for basic research. The pressure of work on immediate problems is proof of the value of the Establishments' work, but it does give urgency to this need. During the war basic work was largely suspended, but its restoration is gradually being effected to bring about a proper balance between short-term and basic work. The choice of problem for the Research Associations rests with their Councils and the programmes represent the best opinion on the various industries as to the problems whose solution can but assist their progress.

While the results of research, conducted in a firm's laboratories, can be appraised as the research proceeds so that new or modified production can be absorbed with current manufacturing activities of the particular firm, it is not so easy to ensure that the results of research conducted outside a firm's laboratories can be brought with the main stream of industrial activity. This aspect of research work conducted by the Establishments and the Research Associations is being given the closest attention with the object of avoiding the risk that valuable results may be left high and dry in the laboratory. This difficulty has been appreciated for many years and one of the methods to overcome it has been the use of large size or pilot plants to enable the laboratory work to be carried into the development stage. This method is proving invaluable in the Cast Iron Research Association Laboratories and the Non-Ferrous Research Laboratories, to name only two, where full scale investigations can be conducted on furnaces, rolling mills, foundries, etc. In the laboratories of the Production Engineering Research Association, a report of which is given elsewhere in this issue, this method would seem to be essential. Another one of the more recently established laboratories which carries its work to the development stage is the Pametrada Research Station. It provides full scale testing facilities for marine turbine propulsion machinery to meet the maximum requirements for both naval and merchant ships and is able to initiate and carry out research for the improvement and development of marine steam and gas turbines and their auxiliary equipment, and the results of such researches can be included in machinery building with the minimum expenditure of time.

Although, with much of the research work done in laboratories outside works, pilot or full size plants are invaluable, they are not always essential, as, in many instances, the results can only be adequately developed in the works and the gap that exists between outside laboratories and the work embraced by the industries they cover is, in too many cases, still very considerable. In those works employing a relatively high density of technically trained men it is comparatively easy to apply the results of research, but in other works in which the technical training of the staffs is at a low density the gap is almost insurmountable. A very valuable means of reducing this gap are the liaison services which have been developed by which members of the staff of an Association regularly visit member firms to assist them in dealing with their technical problems and in applying the results of the Association's work.

In order to ensure that the results of laboratory work are not neglected we are of the opinion that the liaison services could be usefully extended. Under present conditions the time that a research worker is in a particular works to assist in dealing with a technical problem is limited ; if this time could be extended to, say, a month, much could be done, in co-operation with the management, to effect improvements in a number of directions and it would give research workers the opportunity of intimate association with practice that is not less important to the research worker than technical knowledge is to those actually producing. It is in the works and on the floor of the shop that much of the work in laboratories must be given expression and brought to fruition and the research worker can do much to expedite development without in any way retarding the initiative of individual firms.

*Published by H.M. Stationery Office, price 5s. 6d. net.

Grey Ironfounding

Productivity Team's Report

THE Productivity Team from the Grey Ironfounding Industry, which visited the U.S.A. early this year, has presented a unanimous and comprehensive Report* which contains many recommendations for increasing productivity in this country.

Grey ironfounding is a term used for the general and jobbing sections of the industry, in which foundries normally change the patterns frequently and produce a small number of moulds from each. As, however, the line dividing jobbing from specialised foundries is indefinite and the Team saw in America much work concerned with the repetitive production of castings in highly mechanised foundries, the Report is not confined to work of a purely jobbing nature and it is hoped that all sections of the industry will benefit from it. A copy is being sent to every known iron foundry in Britain—there are some 2,000 of them—in the hope that all will take steps to benefit from the discussions arranged on the issues raised.

In order to obtain a general picture of conditions in Britain, the Team visited 29 jobbing foundries before leaving for America, where 24 of the 2,500 foundries in that country were visited. It is pointed out that the British industry has much to be proud of since the war. Its output has increased yearly; it has begun to effect real improvement in working conditions; it has improved its organisations for training, research and development; and, most important of all, production per man is increasing, though slowly. All this has been achieved in spite of some deterioration in coke quality, shortages of suitable pig iron, of labour and electricity, and, above all, of plant and capital to purchase plant. If there is room for a certain amount of pride, there is none whatever for complacency, for, as a result of its investigations in the two countries, the Team concludes that, while the best in Britain may equal the best in the U.S.A., average productivity in America is about twice as high as in this country.

In attempting to determine the reasons for this difference, a number of factors were considered by the Team, and it is evident from the conclusions reached that efforts will have to be made, by Government, managements and workers alike, if that greater production per head, which is not only desirable but essential if Britain is to recover her economic status, is to be achieved. In contrasting conditions on the two sides of the Atlantic, the report summarises the conditions prevailing here and the problems facing the ironfounding industry in Britain. Amongst the latter, reference is made to the lack of effective incentives for labour, management and capital; insufficiency of skilled and unskilled labour; inefficient use of productive time; difficulty of obtaining and financing new plant; insufficient use of costing; working conditions; and raw materials. The Team consider that little good will come of simply leaving matters on the Government's doorstep, although the policy of exporting plant which could be used to improve our own industries is called into question, and the Team is "dismayed" at the pessimistic official forecasts on the rate of bringing into use new electrical generating plant, without which all talk of mechanisation becomes a farce. It is felt that the problems created by high taxation, fewer apprentices and the insufficiency of skilled labour are difficulties which will continue for a long time, and that steps should be taken to undertake reorganisation of foundries accordingly.

Perhaps the most important factor governing the higher outputs in America is the fact that the people there are definitely "production minded." Only two or three generations back they were of hard working farming stock and this may be responsible for the fact that they are conditioned to hard work. With the desire for a higher standard of living go the opportunities for personal advancement in industry, the less restrictive effect of the income tax system, which has no artificial steps deterring a worker from earning more, and the abundance of consumer goods. The Report stresses the importance of this environment factor when compared with Britain where a mediocre standard of living for all, and a high standard for none, kills initiative and enthusiasm in all sections of the industry. Government management and workers should combine to rearrange, the real rewards so that the efficient may be well rewarded and the indolent may suffer some hardship. The Team believes that high productivity is far more dependent on a real stimulus to work than upon the existence of well equipped plant.

That is not to suggest that there is no room for improvement as regards equipment, and in this connection the Report draws attention to the advantages to be gained from the greater use of power, mechanical aids and unskilled labour in increasing the proportion of the skilled operatives' time spent on skilled work. It is pointed out that, in some jobbing foundries in Britain, the skilled moulder often spends little more than half his time in making moulds, the remainder being occupied in general labouring and kindred duties. The greater use of power and mechanical devices affects every stage of production, and ingenious gadgets are used to assist in even the simplest operations. This section of the report, dealing with technical matters, is dealt with elsewhere in this issue in an account of a Conference on the technical aspects of the Report, held on October 12th–13th.

Management in U.S. foundries is very efficient and progressive, and the comparative absence of class distinction in the foundry permits free and easy discussion of any problem. It came as a surprise to the team to find that even close competitors are readily shown the production methods of their rivals.

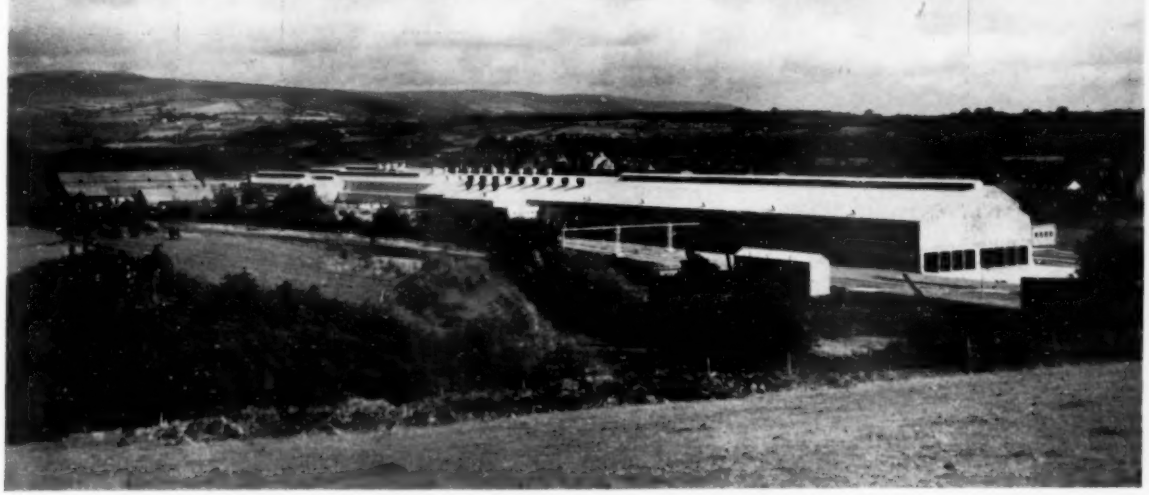
One of the features which obviously impressed the team deeply was the high degree of co-operation between management and workers, which was aided by the local autonomy of the unions. All workers in the same shop are in the same union, the local branch of which negotiates with the company wage scales for each job for the ensuing twelve months. This "local outlook" also has a bearing on the greater borrowing facilities from the banks. Instead of being on a national scale, most of the banks are "local" with, consequently, a much greater interest in ensuring the prosperity of their area.

Other causes of higher productivity mentioned by the team are, the efficiency of the floor executives; careful time study; greater human energy (causes of which include climatic conditions, better food, the still surviving pioneering spirit and the influx of the more enterprising members of European races); and training and education with a greater bias towards industry.

* Copies of the Report (price 3s. 6d. post free) can be obtained from the Anglo-American Council on Productivity, 21, Tothill Street, London, S.W.1, or the Council of Ironfoundry Associations, Crusader House, 14, Pall Mall, S.W.1.

A Continuous Aluminium Strip Mill

Modern Production Methods at Rogerstone

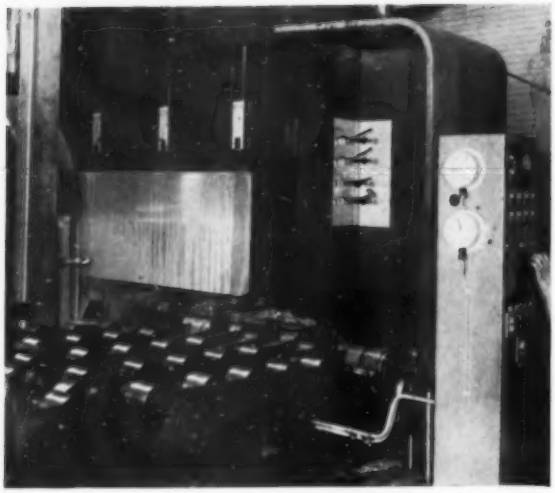


The opening of the new continuous strip mill for rolling aluminium at the Rogerstone Works of the Northern Aluminium Company is an event of considerable importance in our industrial history. This plant, comparable with any in the world, will increase the country's aluminium sheet capacity by 35%, and it is expected that the modern production methods in use will result in a lowering of the cost of the product and so increase demand both at home and overseas. In this article a brief account of the equipment and methods is presented.

FACED, in 1945, with the necessity of absorbing the output of its fabricating plant, considerably increased in capacity since 1939, the aluminium industry set about the task in the same aggressive spirit as that in which it had tackled the converse problem—that of increasing output to meet the needs of the aircraft industry during the war. The success which has attended the drive to find new uses for aluminium and its alloys has been remarkable, particularly in the field of building, where extruded sections and both flat and corrugated sheet have found numerous applications. It was early realized that, to maintain the advances already made by the industry, let alone break into new markets, strenuous efforts would have to be made to reduce costs by the adoption of the most up-to-date equipment and production methods and by standardisation of products wherever possible.

A notable example of a plant based on considerations such as those outlined above is afforded by the Northern Aluminium Company's new continuous strip mill at Rogerstone, which was opened on September 21st by the Minister of Supply, the Rt. Hon. G. R. Strauss. In this plant, high-speed rolling is combined with efficient mechanical handling to achieve the aim of maximum output at minimum cost. Some idea of the extent to which handling has been reduced can be gauged from the fact that it is expected that the output per man will be five times as great as the best that has been attained hitherto in this country by mills making similar products.

The site of the plant has an interesting industrial history, for it was in the year 1772 that a copper works was started by the Royal Mint Company among the ruins of a twelfth-century castle. Later it became a steel and tinplate works and was subsequently taken over by Guest, Keen and Nettlefold for the production of rod, wire and nails. Between the wars, the works fell into disuse but, just prior to World War II the Government, pursuing its policy of locating industry in what were then regarded as distressed areas, chose the site for the manufacture of aluminium products. The plant was erected in 1939 and worked throughout the war for the Ministry of Supply, from whom it was purchased by the Company in 1945. Adequate space was available for extensions, and the advantages which originally located the works at Rogerstone would benefit any new plant. These advantages include availability of labour, the proximity of collieries and carbonising plants for the provision of coal, coke and gas, adequate electricity supply, abundant soft water suitable for process use, and excellent road and rail facilities linking with the Bristol Channel ports where raw material from Canada is unloaded. Furthermore, an important consideration where heavy plant is to be installed, the subsoil is such that piling is unnecessary.



Scalping an ingot in the Ingersoll milling machine.

The new plant, which was erected at a cost of three and a half million pounds and comprises hot- and cold-rolling lines together with the necessary auxiliary plant, has been laid down with an eye to future extensions as the need arises. The present output capacity is 50,000 tons per annum of sheet material, which represents an increase of no less than 35% of the country's present sheet rolling capacity. The hot line works only one shift a day at present, but space is available to increase the cold-rolling capacity threefold. Moreover, should the need arise for the production of strong alloys in the mill, provision has been made for the addition of two further mill stands in the hot line.

In all mass production and continuous processes, standardisation of product is an essential requirement if costs are to be kept as low as possible. To this end, the mill has been designed for, and its output will, in general, be confined to, the two alloys for which there is the most consistent demand, namely, commercially pure aluminium (Noral 2 S) and the 1·25% manganese alloy (Noral 3 S). Both are work-hardening materials possessing good forming characteristics with adequate mechanical strength and excellent corrosion resistance. These materials will be available from the mill in the form of medium-gauge building sheet (flat or corrugated), container sheet, circles (for hollow-ware manufacture), and foil stock (for re-rolling into "silver paper"). Furthermore, as the capacity of the hot-rolling line is at present greater than that of the cold mill, it will be possible to supply 0·1–0·25 in. thick hot-rolled slab, mainly in pure aluminium, in the form of coils or flat plate. Should the need arise, of course, heavier plate could be produced for general engineering and ship-building purposes. The maximum width of flat medium gauge sheet available will be 56 in. and of corrugated sheet, 32 in., the maximum length being 20 ft. in both cases. Container sheet (0·008–0·018 in. thick) will be available in the usual tinplate sizes and up to about 36 in. ×30 in. For foil manufacture the stock is supplied annealed and in tight-wound coils weighing up to 2,000 lb. (3,500 ft.) at a thickness of 0·018 in. and in widths up to 28 in. The rolling, finishing and circle-stamping equipment installed for sizes up to 8 in. diameter should reduce manufacturing costs appreciably and so ensure a steady demand.

Outline of Processing

The ingot for rolling, either imported from Canada or cast in the remelt department, is first "scalped" to remove surface roughness. After pre-heating it is passed down the hot line for successive hot rolling through two independent reversing mills followed by two hot-finishing mills operated in tandem, being end-sheared and side-trimmed in process before being coiled at the end of the line. After cooling, the coil is then transferred to the cold-rolling mill where it is passed through three mills operated in tandem. Subsequent treatment depends on the use for which the sheet is required. Coil intended for building sheet is passed to the heavy shear line where it is flattened, cut to length and corrugated if required. Coil for any other purpose passes on to a slitter where it is edge-trimmed or slit into strips. If intended for "circles" for hollow-ware, it goes to the circle mill where the discs are cut on a blanking press. Other material is put through the annealing furnace. After annealing, foil stock is in the condition required by the customer, but container sheet is rolled to the required hardness in a temper mill before being delivered to a continuous-type light shear line for de-greasing, edge trimming, checking for gauge and quality, cutting to length, and, finally, sorting. The plant has been laid down to the general specifications of the Company's own engineers, who have supervised the installation.

Melting Facilities

As it is intended to import ingots up to 4,000 lb. in weight direct from the Canadian reduction plants, the melting equipment installed deals only with process scrap, which is mainly light gauge. For this purpose, low frequency induction heating, with its rapid melting, good circulation and reduced oxidation losses, was chosen as being most suitable, and two Siemens-Schuckert and two Birlec Tama furnaces have been installed.

The former, supplied by 400 kW transformers, have two baths connected by horizontal channels enveloped by induction coils. Only 7,400 lb. of the 10,900 lb. capacity is available for tapping, as the metal in the sump forms part of the inductive circuit. 6,000 lb. of metal are melted every three hours. The Birlec Tama furnaces have a single bath with vertical melting channels passing down through a detachable inductor unit to a horizontal connecting channel. The rating is 500 kW and 7,500 lb. of metal are melted per three hour cycle.

Temperature control in each case is effected by varying the transformer tappings in response to a bath thermocouple operating in conjunction with a Kent instrument.

Economic and technical considerations make it desirable to keep the furnaces melting at full rate for as much of the available time as possible. Four simple electric resistance holding furnaces, with nickel-chrome-iron roof heating elements, have, therefore, been designed by the Northern Aluminium Company; in these the metal can be held at a steady temperature by the use of a Kent controller. Transfer from the melting furnaces is effected, at 2,000 lb./min., by a syphoning arrangement. The capacity of each is 11,000 lb. of metal and the bath is tapped, from a spout in the corner, into one of two

semi-continuous casting units. The latter are arranged to cast two 4,000 lb. ingots simultaneously through a branched runner, but a single ingot, 60 in. × 12 in. in section, can be produced if desired.

From these furnaces it is possible to cast sound rolling ingots from process scrap alone, without addition of virgin materials.

Ingot Scalping

As cast, the surface of the ingot is sometimes rough and unsuitable for rolling. In such cases, both faces are milled to a depth of about $\frac{3}{16}$ in. in an Ingersoll horizontal spindle milling machine, which has a 74 in. diameter cutting head, holding 42 roughing and two finishing tools. This machine is capable of milling a face 10 ft. × 5 ft. and both sides of an 8 ft. × 4 ft. ingot can be machined in less than five minutes.

THE HOT MILL LINE

Preheating for Rolling

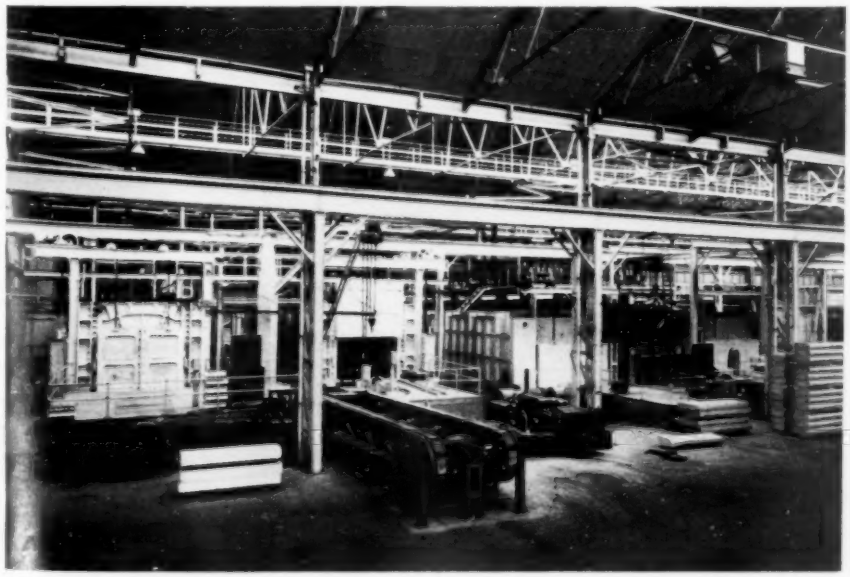
Aluminium alloys are hot-rolled in the temperature range 420°–550° C., depending on composition. Certain alloys require a soaking period at temperature and the pre-heating plant installed, two gas-fired and two electrically heated furnaces, is sufficient to supply the hot rolling line for one shift in such cases. Provision has been made for the installation of further furnaces to enable the hot line to work continuously on any alloy. The furnaces are of the " push through " type and are operated on the batch system.

The two Priest gas-fired furnaces were existing when the mill was started. Each has a single arched chamber, 51 ft. × 9 ft. × 6 ft. high, divided into eight zones. Air and producer gas ducts to each zone are primarily controlled by manual valves, but an independent by-pass on each duct is motor-operated by a controller (one per zone) responding to a roof thermocouple. Hot gases from the burners mix with re-circulated gases in a vertical duct leading to the space above the chamber arch.

A close-up of centrifugal fan and bank of heating elements with screen removed.

Through openings in the arch, they pass down through the charge and out through the floor into a central flue leading to the re-circulating fan. " Spillage " is removed by two cast-iron stacks, one fitted with a CO_2 recorder.

The G.W.B. electric furnaces are 58 ft. long, internally, and ring arches divide the chamber into six zones, in the roof of each of which is a 15 H.P. fan by which air is circulated over the heating elements, down through the hollow walls and up through the charge. The elements, which are screened from the charge by refractory slabs, take a load of 3,750 kW during heating up, but are maintained at temperature by 85 kW in the end zones and 55 kW in the other four zones. The furnace trays are cast in heat-resisting alloy, and each has two cast rollers on stainless steel shafts. Temperature control for each zone is provided by a Kent " Multelec " Mark II indicating controller, and a Kent six-point continuous chart recorder is incorporated in the control panel.



The charging end of the four preheat furnaces, the two on the left being gas-fired and those on the right electric.

Each pair of furnaces has a heavy duty double-chain conveyor, extending back into the scalping bay, on which ingots are loaded prior to weighing and charging into the furnace. On the exit side, the ingots are picked out of the front of the furnace by a Wellman-Smith-Owen overhead peel-type handling machine which places the ingot on to a tilting table, where it remains until lowered on to the roller table when the breaking-down mill is ready to receive it.

The hot-rolling line, which is a third of a mile long, comprises breaking-down

The exit end of the preheat furnaces, with the ingot on the tilting table before being lowered on to the live-roll table.

and intermediate reversing mills, a two-stand tandem hot-finishing mill, and a coiler, together with the necessary auxiliary equipment.

Breaking Down Mill

The two-high reversing breaking-down mill, by Brightside Foundry and Engineering Co. Ltd., has 35 in. diameter × 96 in. face forged steel rolls. The mill is provided with electric top-roll balance and the two-motor screwdown gear is fitted with magnetic couplings for individual adjustment and has a screwing speed of 45 in./min. A 2% Sternol-soft-water emulsion is used for cooling the rolls and for flood lubrication of the roll neck bearings, which are of bakelised fabric in cast steel chocks. Provision is made for straining and cooling the coolant.

The main drive is by a direct-coupled B.T.H. 40–51 R.P.M. reversing D.C. motor, rated at 2,000 H.P., through a universal slab-type coupling, which gives a maximum rolling speed of 450 ft./min. The 108 ft. ingoing roller feed table and the 94 ft. outgoing table, both with chilled cast-iron rolls, are synchronised with the main drive. On the outgoing side, the last 24 rollers may be controlled by the operator of the intermediate mill.

In the breaking-down mill, the thickness is reduced from 9 in. to 2½ in. in five or more passes and a split roller table on the ingoing side provides for turning the ingot so that the first few passes may be carried out with the ingot broadside. To centralise and straighten the material a pair of pushers is provided on each side of the mill.

Intermediate Mill

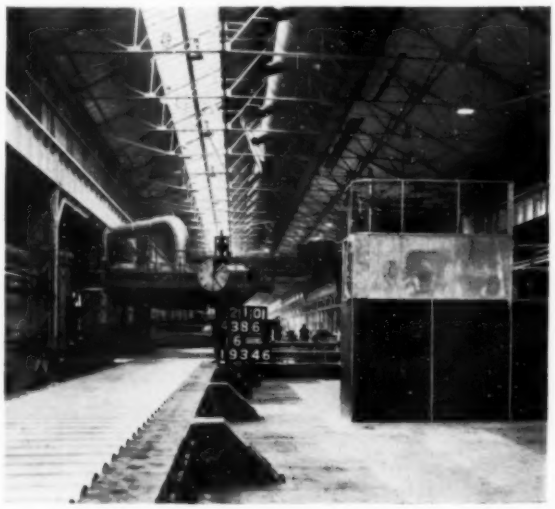
The intermediate mill, also by Brightside, is generally similar to the breaking down mill but is somewhat smaller. It is provided with 32 in. × 84 in. forged steel rolls and is driven by a 1,650 H.P. B.T.H. motor, which runs at the same speed as the breaking-down mill motor. The rolling speed is 420ft./min. A 3% Sternol-soft-water emulsion is used for cooling.

The ingoing roller-feed table is 86 ft. long (making 180 ft. between breaking down and intermediate mills) whilst the outgoing roller table extends 45½ ft. towards the hot-finishing mill. In addition to centring pushers, automatic hydraulically-operated side guides are provided, which close to give a slight clearance to the slab on the ingoing side and open wide on the outgoing side, the settings reversing with the mill.

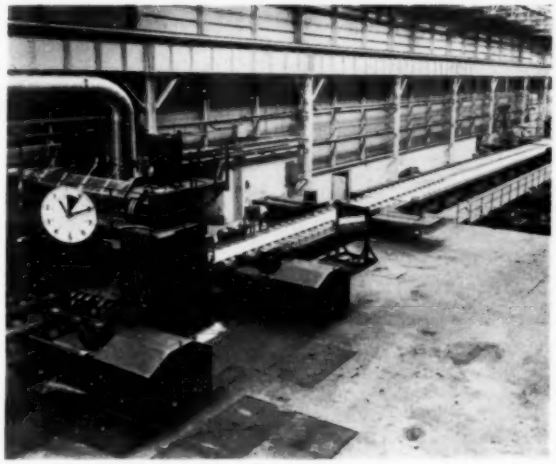
On leaving this mill, in which three or five passes reduce the thickness to ⅜–¾ in., the slab, which may now be 150 ft. long, is carried along a 196 ft. Robertson live-roller table to an up-cut shear. The rollers in this table are of tubular steel, chromium-plated to reduce pick-up of metal particles and damage to the strip surface, and centring pushers are located at the mid-length.

The up-cut shear, supplied by Head Wrightson Machine Co. Ltd., has a capacity of one inch thick hot aluminium plate up to 80 in. wide. To facilitate entry of the slab into the finishing mill the blades are set to produce a vee cut (apex forwards). In front of the shear is a pair of articulated guides for straightening the slab before cutting. Scrap is handled by a New Conveyor Co. double chain slat conveyor.

Thirty feet from the shear is a rotary edge trimmer, which is a conversion of a machine built in 1940 by Head Wrightson, now capable of trimming hot aluminium



The 2,000 H.P. breaking-down mill at the beginning of the Hot Line. Note the aluminium-panelled control cabin and the aluminium fume-exhausting ducting.



The intermediate reversing hot mill, second in the Hot Line.

alloy slab up to 0·6 in. thick. Edge scrap is chopped by Loewy flying shear type cutters.

Hot-Finishing Mill

The slab next passes to the two four-high stands of the Robertson tandem hot-finishing mill where, in one pass, it is rolled down to the gauge required in the final coil (0·100–0·250 in.) This may represent a reduction of 80%, giving a final length of product up to 600 ft. Provision has been made for the installation of two further stands to this mill should the need arise.

The two stands are spaced at 19 ft. centres, with electrically operated loop control rollers between the two stands and at inlet and outlet of the train. The work rolls, 24 in. × 88 in., are of forged steel of Shore hardness 70°. For the steel back-up rolls, three types are available, forged, cast, or composite (all of 50°–55° Shore hardness). Withdrawal of the back-up rolls is effected by a sledge and portable motor-driven winch, whilst the work rolls are handled by a porter bar slung from an overhead crane. Roll journal bearings are of the Robertson oil-flood-lubricated type, with white-metal-lined sleeves carried in cast steel chocks. Axial location of the work rolls is by tapered roller bearings. The work-roll chocks are located within the horns of the back-up roll chocks by means of wedges which can be adjusted to off-set the work rolls by as much as $\frac{3}{8}$ in. Hydraulic rams in the roll chocks carry the weight of the rolls. A 10% Sternol-soft-water emulsion is used for cooling the rolls.

The work rolls of the first stand are directly driven by a B.T.H. 3,000 H.P. D.C. motor which, running at 48–96 R.P.M. gives a rolling speed of 300–600 ft./min. A 2,600 H.P. motor, running at 200–400 R.P.M., drives the second stand through a 1·57 : 1 reduction gear, the rolling speed being 400–800 ft./min.

Two-motor screw-down gear operates at 0·25 in./min. and can be controlled at a small cabinet on each stand. On the ingoing side of each stand is a set of heavy mechanically adjustable guides by Davy and United.

Trimmer and Coiler

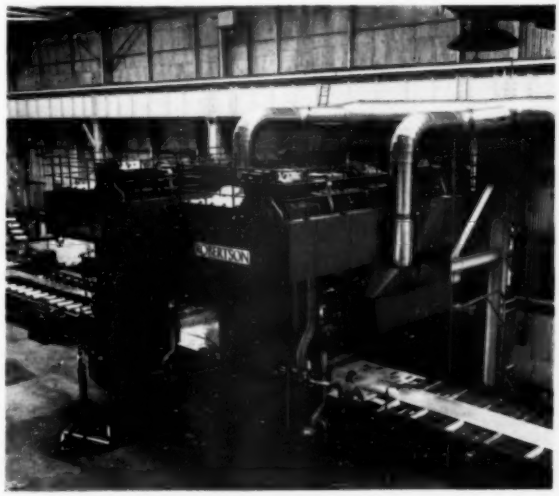
Leaving the finishing mill, the slab travels along a 700 ft. long Robertson roller table to the coiler. Each of the 218 rolls is driven by a separate 1 H.P. Laurence, Scott and Electromotor induction motor and is made of chromium plated tubular steel. The table is divided into three separate sections, each or all of which can be controlled from the hot finishing mill cabin or from the run-out table desk at the end of the line. Hydraulic centring pushers are located at intervals along the line.

After leaving the finishing mill the slab has to be cooled to a temperature low enough for good coiling and this is done by means of water sprays. It then passes to the end of the run-out table where an 84 in. wide Brookes down-cut shear trims the front end and cuts it to length if necessary. Following the shearing operation a Head Wrightson rotary trimmer, which can deal with strip up to 0·2 in. thick at 800 ft./min., trims the edges. The trimmer drive is a 100 H.P. Laurence, Scott and Electromotor commutator motor.

Beyond the edge trimmer, a five-roller table, controlled as part of the run-out table, leads, via a set of parallel guides, to the Wellman-Smith-Owen three-roll up-coiler, driven by a Laurence, Scott 150 H.P. commutator motor, where strip up to 0·2 in. thick can be coiled at the rate of 800 ft./min. When complete, the coil is ejected onto a vee roller gravity conveyor, where it is weighed before being rolled off on to a double-strand chain conveyor, fitted with wooden nesting blocks, from which the coils are removed to a cooling park alongside the run-out table.

Throughout the hot-rolling operation the temperature of the stock is checked by a low-temperature radiation pyrometer made by British Electronic Products Ltd. This instrument, believed to be the first of its kind ever employed industrially, can reliably indicate temperature down to 150° C., or, in certain circumstances, down to 100° C. Measuring heads are situated at the tilting table, at the ingoing end of the hot-finishing mill and immediately after the cooling sprays on the run-out table. The temperatures are indicated in the appropriate control cabins.

In order to keep the widely spaced units working in harmony, microphones and loud speakers are fitted in the operating cabins, for issuing instructions and inter-communication.



The tandem four-high mills in which hot rolling is completed.

COLD WORKING PLANT

Tandem Cold Mill

Coils which are to be cold rolled in the new mill are deposited six at a time on to a slat conveyor which passes them to the 3-stand tandem cold mill in No. 1 finishing bay. This mill has an interesting history in that the centre stand, built by the United Engineering Co., U.S.A., was on the high seas bound for Paris, at the time of the fall of France in 1940. The ship put in at Liverpool and the mill was sent to Rogerstone where it was installed in line with one of the reversing hot mills in the East works. When the new mill was being planned, it was decided to use it for its originally intended purpose, in a three stand tandem mill. Two similar stands were, therefore, ordered from Davy and United Engineering Co. Ltd. The complete unit will roll coils up to 4,000 lb. in weight, with a width of 20–56 in. Its outstanding characteristic is its high speed, the finished strip emerging at 2,000 ft./min. The reduction at one pass through the mill may be as high as 90%, but with alloys which work harden quickly two or more lighter reductions, with intermediate annealing, may be necessary.

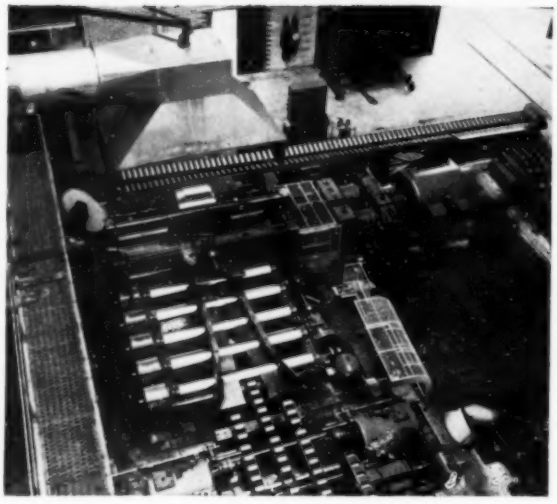
The work rolls, 18 in. × 66 in., are of 100° Shore hardness forged alloy steel, running in Skefko bearings. For backing-up there are 49 in. × 66 in. forged steel rolls with a 75°–85° Shore hardness, those in No. 1 stand running in Skefko roller bearings whilst those in Nos. 2 and 3 stands have Morgoil bearings and a Skefko thrust bearing at one end. Cast steel chocks, fitted with hardened steel wearing plates are used without wedges on work and back-up rolls. Endwise location of the back-up roll chock is provided by plates bolted to the housing at the roll-change side only, but the work-roll chocks have latches engaging in slots in the back-up roll chocks. The back-up rolls are centrally mounted in the mills and the work rolls are displaced $\frac{3}{8}$ in. forward from them. Hydraulic balancing cylinders for the upper rolls are built into the lower chocks.

The three main stands are driven by B.T.H. non-reversing D.C. motors of 2,600 H.P., the first two having speeds of 200–400 R.P.M. and the third 280–450 R.P.M. Reduction gearing (1·74 : 1) is used on the first stand only. The corresponding mill speeds are: first stand, 540–1,080 ft./min.; second stand, 943–1,886 ft./min.; and the third stand, 1,320–2,120 ft./min. Internal gear type flexible couplings are used for connections to the motors, as speeds are too high for the usual slab couplings. Two-motor screwdown gear, fitted with magnetic couplings, operates at $\frac{1}{4}$ in./min., Selsyn indicators showing the position of the screwdown to 0·001 in.

A paraffin-base oil is used for cooling and lubricating the rolls, and extensive oil circulating and cleaning systems are provided, since the maintenance of the oil in a perfectly clean condition is a most important factor in the production of first-class cold-rolled strip. The pipes in the cleaning system are mainly of Argonare welded aluminium alloy to ensure freedom from scale.

The Morgoil bearings for the back-up rolls are pressure lubricated with oil, whilst a Farval automatic grease lubrication system serves the Skefko bearings and other bearings in continuous use.

Before entry into the first stand, the coils have to have the end bent back in a spragging machine. This produces an 18 in. tail which is lengthened by feeding into a Robertson five-roller leveller containing a shear with which the end is cut at a slight angle. Reversal of the leveller ejects the coil on to a slat conveyor, holding five coils, on which it moves up to a hydraulic ram which lifts it up to the mill cones. The coil is fed into No. 1 stand through an interlocking roller bridle which holds it under tension and keeps it in the centre of the rolls. It is then passed to Nos. 2 and 3 stands, over a deflector roll, and recoiled on a collapsible driven reel, the whole mill meanwhile running at a relatively slow speed until the reel has been wrapped with several turns. All three stands and the reel are then accelerated as a unit to the proper rolling speed. During the accelerating period, special electrical devices are used to maintain the correct tension. Between stands, and after No. 3 stand, the gauge is measured by flying micrometers of the Pratt and Whitney type, supplied by Messrs. Taylor, Taylor and Hobson.



The edge-trimmer and coiler showing the adjustable entry guides with the last five individually driver live-rolls; the "Vee" roller gravity conveyor, the weighing stand and, on the right, the discharge section from which the coils are in turn ejected on to a slat conveyor.

After stripping from the reel, completed coils are placed on a receiving table where they are banded, released down a vee-roller conveyor, across a weighing section, to one of two slat conveyors from which they are lifted on special beams.

Subsequent movements of the material depend on the nature of the finished product. Coil required for building sheet is transferred by crane to the heavy shear line in No. 2 finishing bay. All other coil is passed forward to the slitting line for edge trimming and slitting.

60 in. Heavy Shear Line

From the tandem cold mill, building sheet coils pass to the Robertson heavy shear line for converting into flat or corrugated sheets.

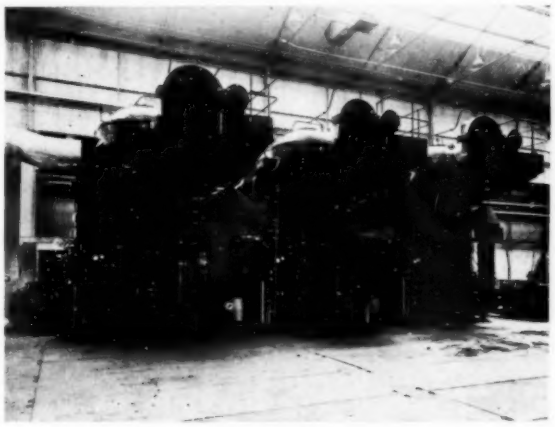
The coils are unwound on cones before passing to the flying shear and leveller, which is a standard Hallden-Robertson No. 55 machine with a rocker guillotine type flying shear. Strip up to 56 in. width, 0·022–0·064 in. gauge can be cut at 0–300 ft./min. into lengths of 30 in. — 20 ft. with a tolerance of ± $\frac{1}{32}$ in. The accelerating table belt, which can be driven at 350 ft./min.,

separates the sheets before delivering them to the combined belt conveyor and stacking frame whose 72 in. wide belt can be driven at 450 ft./min. A skewed roller table, consisting of hardened steel driven rollers skewed at 5°, brings the sheet over to a side guide before delivery to the corrugating machine. The latter is a series of forming rolls driven by a 25 H.P. motor which puts grooves of the required size into the sheet and delivers the corrugated sheet to a piling table. Sheets which are to be finished flat or corrugated in some other type of machine are stacked as they are delivered from the flying shears, one section of the conveyor tables being retracted out of the way.

Slitting Line

The slitting line consists of a rotary-knife edge-trimming and slitting machine served by a drum pay-off reel and tension reels, all by Head Wrightson Ltd. Alloy of a maximum gauge of 0·064 in. and a maximum width of 56 in. can be given four simultaneous cuts at speeds up to 1,000 ft./min. ; thinner material may be cut into eight strips.

The coil is fed by mechanical charge on to the pay-off reel which is provided with a drag generator ; this applies



The 3-stand tandem cold finishing mills which roll at 2,000 ft. per minute.

tension to the strip as it enters the rotary slitting cutters and is wound on to reels at the other side. The coil on each tension reel is ejected mechanically and passed over a weighing machine on to a slat conveyor. The edge trimmings are let down into a tunnel and rolled up by means of a scrap baller into a size suitable for subsequent remelting. All coils except those intended for the circle line in No. 2 finishing bay now pass to the annealing furnace where the material is softened for further rolling. Foil stock is usually given an anneal at the final gauge so as to be suitable for reduction to foil gauges at the foil rollers' plant. In the production of container sheet, an intermediate anneal is given, before rolling in the temper mill.

Annealing Furnace

The heating medium for the Priest parallel-twin-chamber continuous annealing furnace is clean hot air, circulated in a closed system through direct gas-fired tubular heat exchangers. These stand alongside the annealing chambers and are connected thereto by overhead insulated delivery mains and underground return flues. Dividing doors, interlocked with the charging mechanism, separate each chamber into pre-heating and soaking zones capable of attaining temperatures of 500° and 550° C. respectively through circulating air. Each chamber contains 21 carriers, each supporting two coils horizontally.

Coils are loaded by overhead crane and loading beam on to carriers standing on an outside runway ; these are mechanically transferred, singly, to the charging end of the furnace. Coils and carriers are pushed through the furnace by twin Fielding and Platt hydraulic pushers, one opposite each furnace chamber, each capable of giving a 35 ton thrust over a 6 ft. stroke. After annealing, the coils are extracted mechanically and transferred to an outside runway where they are off-loaded.

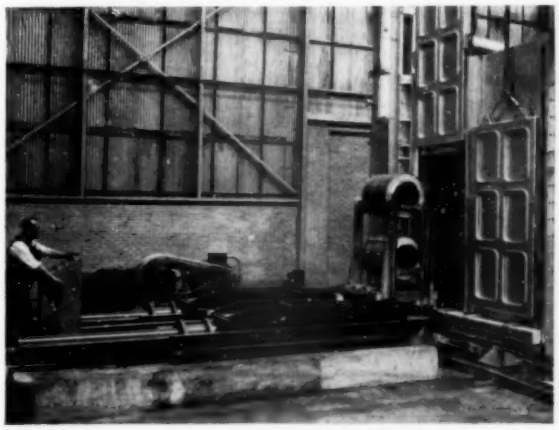
The annealing chambers are 80 ft. long, each 4 ft. 6 in. wide × 9 ft. 6 in. high and provide a continuous throughput of 7½ tons/hour. Suitable precautions are taken to avoid uneven heating of the load and the control panel houses 5-Foster 6 point temperature recorders, 2-Foster controllers, 2 Electroflo integrating and recording flow meters for gas and air, 1-Negretti and Zambra pressure controller, and 2 manometers.

Temper Mill

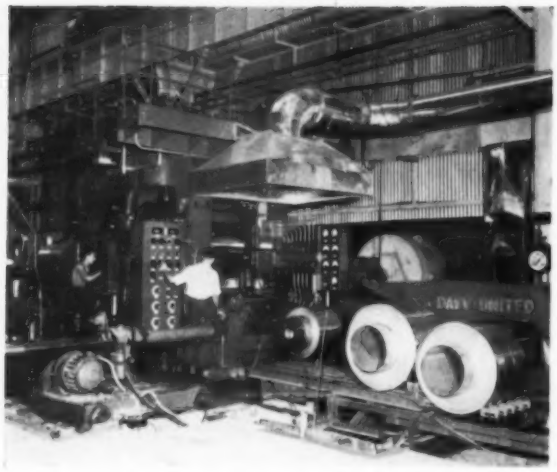
The mechanical properties of the work-hardening alloys depend on the degree of cold-rolling reduction they receive after annealing. Container sheet may, therefore, be given any temper by rolling to a predetermined degree of reduction (say 30–60%) in the temper mill.

This four-high non-reversing mill by Davy and United is designed to roll strip of 14–30 in. width from an ingoing thickness of 0·04–0·01 in. to a final gauge of 0·016–0·007 in. at speeds up to 2,000 ft./min. The greatest coil weight which can be accommodated is 2,000 lb.

The work rolls are 12 in. × 36 in. and of forged alloy steel hardened to 100° Shore. Back-up rolls are 32 in. × 36 in. and of forged alloy steel of 75–85° Shore hardness. All roll neck journals are carried in Timken double-row tapered roller bearings lubricated from the Farval high pressure grease system common to both cold mills. The chocks are of similar design to those in the tandem mill and the work rolls are offset ⅛ in. towards the outgoing side of the back-up roll centre line.



A pair of coils, wound on steel spools and mounted on a tray, entering the annealing furnace.



The four-high temper mill can roll container sheet to the desired temper at 2,000 ft. per minute. Note aluminium fume-exhaust and ventilation ducting.

Power is provided by a B.T.H. 1,000 H.P. 500/1,000 R.P.M. D.C. motor driving directly through a Croft's internal gear-type coupling. Two-motor screwdown gear, fitted with magnetic coupling, operates at 0·2 in./min.

For cooling and lubrication of the rolls, the temper mill requires a slightly lighter oil than the tandem mill and a white-spirit-based oil is used. This is sprayed on the ingoing side only, air blasts being used on the outgoing side to blow off as much oil as possible.

As this is the final rolling, it is important that the product shall be perfectly flat and of uniform gauge. As a check on the latter, thickness is measured by a Pratt and Whitney type flying micrometer or, on thicknesses up to 0·028 in., by a Baldwin radiation thickness gauge, which employs a radio-active material, Thallium 204.

The strip passes through the mill once only, from the unwind reel to the Head Wrightson collapsible reel on the outgoing side. Tension in the ingoing and outgoing strip is controlled electrically.

Light Shear Line

From the temper mill, the coils pass to one of two light shear lines. No. 1 line comprises handling equipment, uncoiler, spot-welder (with shears), wash box, edge trimmer, instrument stand, leveller, rotary shear, classifiers and pilers. No. 2 line is similar but an edge trimmer is not at present included. Each line is capable of shearing 36 in. wide material, 0·038 in. thick at speeds of 200–600 ft./min.

From the uncoiler the strip passes through the spot welder where to obviate threading of the line, the front end of each fresh coil is fastened to the rear end of the previous one by spot welds, made by Sciaky type P.S.A. 50 dual units. The strip is then passed through the wash box to remove excess oil, leaving just sufficient for further operations at customers' works. After edge trimming the strip passes a flying micrometer or continuously measuring gauge (Magnetic Gauge Co., U.S.A.), which checks the thickness and automatically dictates the rejection of inaccurate material when it reaches a later stage as separate sheets. The strip is cut into flat sheets varying in length between 18 in. and 37½ in. by a Hallden synchronised automatic flattening and shearing machine. The leveller comprises a pair of pinch rolls and 14 flattener rolls, and the shear, two rotating drums driven through a synchronising gear-box, carrying the blades. At 600 ft./min. the accuracy of cutting is $\pm \frac{1}{32}$ in. in the longest sheet.

The cut sheets now pass through a classifier which separates them into three piles according to quality. This is done by moving the sheets over a series of belt conveyors which are provided with two gates; through the first is passed the scrap, i.e. off gauge material detected automatically by the flying micrometer, or material which has been rejected by the inspector by manual operation of a control; through the second gate pass sheets of doubtful quality which the inspector wishes to re-examine. Prime quality sheets pass over both gates and are delivered to a third pile where they are automatically counted and stacked ready for packing and despatch.

Sheet Inspection Line

This line, which is used for re-inspecting doubtful sheets from the light shear line, is 33 ft. long and comprises, depiler, feed conveyor, inspection wheel, two shingling conveyors and piler. Sheets can be handled at the rate of 50–75/min. which is six times as fast as by manual handling.

On the depiler the rear edge of the top sheet is lifted by suckers; a blast of air then separates the sheets and further suckers are attached at the front to lift the sheet on to the inspection conveyor. The operation is entirely automatic and an automatic caliper prevents two sheets passing along the conveyor together. From the conveyor, the sheet is picked up by a spoked wheel which turns it over, thus displaying both sides to the inspector who, by pressing a button, can divert any scrap sheets through a gate in the classifier conveyor after they have left the inspection conveyor. Good sheets are carried over to a pile where they are counted and stacked ready for despatch.

Circle Line

It will be remembered that, in our description, we left the material for the circle line at the slitter. The circle

A 40-ton aluminium crane lifting one of the mill housings of the 3-stand tandem cold rolling mill. This is one of ten aluminium cranes in the mill.

line itself consists of uncoiler, leveller, instrument stand, blanking press, separator, two inspection conveyors, feed conveyors, and pilers.

The uncoiler delivers strip, at a speed of 50–200 ft./min., to the leveller, which consists of six 3·4 in. diameter flattener rolls and one pair of pinch rolls. This machine, which has a maximum capacity of 8 in. width and 0·038 in. thickness, can be moved out of line when blanking material not requiring straightening. The inspection stand is fitted with a Model 21 foil gauge, by Electronic Instruments Ltd., which operates a scrap gate further along the line when off-gauge material passes it. The press, of the Rhodes No. 3 "Ultra Speed" type, is arranged for a maximum strip width of 9 in. and can blank 500 3-in. circles or 250 8-in. circles per minute. Immediately below the press is a separator which forms two parallel lines of circles on the conveyor, thus enabling the forward speed to be halved. A scrap gate slides over the separator (operated by a push button and the thickness gauge) to divert off-gauge and obviously defective circles. The circles are then inspected on one side on the conveyor band, then turned over for inspection of the other side before being brought back to a single stream for feeding to the pilers.

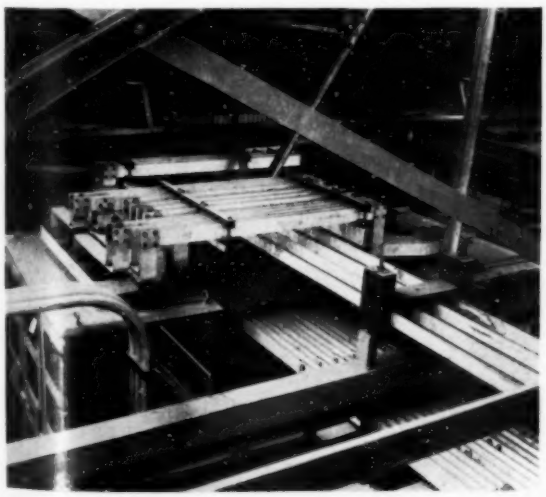
Packing and Shipping

Despatch of all material is made from the extreme ends of both finishing bays. Here space is provided for packing, in which great care is taken to ensure that all products shall arrive in perfect condition, and here also material is assembled ready for despatch. Each bag is provided with loading platforms for lorries and railway trucks, loading being facilitated by a 5 ton overhead crane.

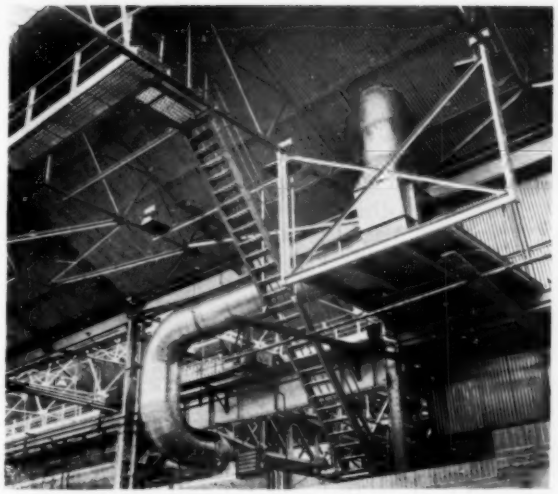
MISCELLANEOUS EQUIPMENT

Handling Equipment

To make the fullest use of the capabilities of modern plant, a very comprehensive handling system has been an essential of the scheme since the beginning. In some cases the type of equipment has been governed by the layout and in other cases the converse has been the case. The layout and handling have been based on the need for minimum manpower, freedom from damage, reliability, and flexibility. Moreover provision had to be made for material to cool-off at certain stages and for ensuring that no machine would ever be idle waiting for material.



Aluminium busbar inter-connections between the low-frequency induction-type melting furnaces and control gear.



Several applications of aluminium are represented here: roof and wall sheeting, roof glazing bars, catwalks, access ladders, cranes, ventilation ducting, and paint.

For handling ingots, use is made of Elwell-Parker electric battery fork trucks supplied by Gillespie Partners Ltd. The ingot grabs at the casting units and the scalping machine were designed and built by Walter Somers and Sons in Noral 17 S. In general, overhead cranes are used for carrying material between the individual conveyors serving each unit or group of plant, special lifting beams, controlled from the driving cab being available for lifting batches of six coils. A number of these cranes were pre-existing, but of the new ones, ten are constructed of aluminium alloy, nine by Wellman-Smith-Owen and one by Sir William Arrol. Reference has been made earlier to the Wellman-Smith-Owen pre-heating furnace discharging machine and to the various conveyors associated with individual plant units. The double chain conveyors on the charging side of the pre-heating furnaces were made by the New Conveyor Co. Ltd., who also supplied conveyors for scrap handling at the upcut shears, and for scrap handling at Nos. 1 and 2 edge trimmers together with the blanking press and disc inspection conveyors and the sheet inspection conveyor.

Rolls and Roll Handling

For the hot mills, Firth Brown supplied forged steel rolls, the hot finishing mill back-up rolls, forged in one piece, being the largest of their type made to date. This company also supplied back-up and fully-hard work rolls for the cold mills. Messrs. Hadfields Ltd. also supplied rolls for the cold mills, the "Hadura" work rolls being of the fully hardened type with a hardness of 100–104 on the 'C' type Shore Seleroscope. The composite back-up rolls for the tandem mill have Hecla 117 alloy steel forged sleeves on heat treated alloy steel shafts, the hardness being 75–85 Shore.

For handling, special roll transfer wagons, manufactured by M. and W. Glazebrook Ltd., are available.

Electrical Equipment

Space prevents more than a passing reference to the electrical gear, which in a big plant such as this, actuated entirely by electric power, is exceedingly extensive and complex. The incoming supply at 66 kV is handled by English Electric and British Electric Transformer equipment, from which it is fed to switch houses and sub-stations where the 11 kV and 400 V switchgear is of Ferguson Pailin design. For cranes, screwdown motors on mills, etc., a 460 V D.C. supply is provided by a 600 kW Crompton Parkinson rotary converter or a 500 kW English Electric mercury-arc rectifier. Reference has already been made to the B.T.H. main mill drives, supplied by 11 kV motor generators, and to the Laurence, Scott and Electromotor equipment on the run-out table and up-coiler. B.T.H. were also responsible for much of the electrical equipment on the shear lines, whilst various items of control equipment were supplied by Donovan Electric and The Watford Electric and Manufacturing Co. Ltd. British Insulated Callenders Cables supplied several miles of cable of various types.

The Use of Aluminium in the New Mill

The extensive buildings housing the mill, together with many items of its equipment, in themselves demonstrate some of the widespread applications of aluminium. In each case the material was chosen because of the substantial economic or functional advantages accruing from its use, and the result is an efficient plant, generally impressive and most pleasing in appearance.

The buildings themselves are of steel framed construction, erected by Redpath, Brown, with brick walls to a height of 8 ft. The upper walls and roof are of double layers of corrugated Noral 3 S sheet separated by aluminium foil insulation, a method of construction which has resulted in a 50% saving in space-heating plant. All ridge-capping, barge boards, flashings and gutters are of Noral 3 S, with downpipes and glazing bars of extruded Noral 50 S.

Inside, the most striking application of aluminium is its use in the overhead cranes already mentioned. Other uses include roof walkways, access ladders, rolling and lifting doors, air ducting for ventilating and space heating. Reference should be made in passing to the ventilation system, installed by Ozonair Ltd., which provides for fume extraction on the hot-mill line, for fume extraction from the cooling oil cellars, and for cooling of totally enclosed motors as well as the provision of a 25,000 cu. ft. min. supply of filtered air No. 20 sub-station. General ventilation is by way of a jack roof and Robertson static roof ventilators, with Robertson extract roof ventilators in areas where there is most process heat to be dissipated.

On the electrical side over a million feet of aluminium cable conduit have been installed and aluminium busbars are employed in several items of electrical equipment. Aluminium is also used in processing operations where freedom from corrosion or scaling is demanded.

Parsons Memorial

A CEREMONY of more than ordinary interest was performed recently by the dedication of a Window in Westminster Abbey to commemorate SIR CHARLES A. PARSONS, O.M., F.R.S., who died in 1931. This is part of the memorial decided upon by a Committee appointed by the Royal Society for the purpose; other parts include the Parsons Memorial Lecture delivered annually, and a contribution of £10,000 towards the Parsons Memorial Library at London House, Bloomsbury, which was opened by H.M. Queen Mary in 1937.

Sir Frank Smith, Chairman of the Royal Society Committee and the first Parsons Memorial Lecturer, delivered the Memorial Oration at the Abbey, in which he referred to Sir Charles A. Parsons as a great man, a great gentleman, a great scientist, and, in the judgement of many, the greatest steam engineer the world has known. He overcame many difficulties, thought to be insurmountable, to produce the first turbo-electric generator in the world. A few years later four turbo-electric generators were supplied and the modern electric power industry may be said to have started with those four engines. But while the development of turbo-generators was a great engineering triumph that of the steam turbine for propelling ships was more dramatic. He planned and built a 100 ft. vessel, the *Turbinia*, which demonstrated the value of steam turbines. Soon afterwards two destroyers were built, each engined with Parsons turbines, which attained a speed of 40 knots.

Welding Research Award

THE Council of the British Welding Research Association have awarded the 1949 Welding Research Prize of £100 to Dr. K. Winterton, Mr. J. G. Ball and Mr. C. L. M. Cottrell for their joint paper entitled "A New Weldability Test for Magnesium Alloy Sheet." This prize has been donated by the British Oxygen Co., Ltd., who have kindly offered to provide a Prize Fund for a competition relating to welding for three years.

The Council have decided that the closing date for entries for the 1950 competition shall be extended to 31st December, 1950. A single prize of £100 is offered again this year and will be awarded for the best paper submitted on a research into welding or its applications. Full details relating to this competition can be obtained from The Secretary, British Welding Research Association, 29, Park Crescent, London, W.1.

"Metamic"—A New Engineering Material

THE MORGAN CRUCIBLE CO., LTD., have for some time been actively engaged in the development of metal-ceramic materials, and have registered the Trade Mark 'Metamic' to cover their products of this type.

Modern methods and techniques have created a growing, and as yet unfulfilled, demand for materials which will operate satisfactorily at temperatures above those at which the present high temperature alloys may be used. Under these severe thermal conditions the conventional ceramics generally fail to combine all the desirable properties such as high strength and resistance to creep and thermal shock. The ideal may be to combine the better features of both metals and ceramics. Considerable interest is therefore being shown in bodies in which metals and ceramics are intimately associated constituting what is virtually a new class of materials.

The research laboratories of the Morgan Crucible Co., Ltd., are developing 'Metamic' materials to cover a wide range of applications. The use of 'Metamic' for turbine blades is one example of the many possible applications for this material, and may enable turbine operating temperatures to be raised to such a degree as to effect a considerable fuel economy.

European Trends in General Galvanising

An Outline of Development Work

At the semi-annual meeting of the American Hot Dip Galvanisers' Association held early this month at White Sulphur Springs, U.S.A., Mr. R. Lewis Stubbs and Mr. A. R. L. Chivers of the Zinc Development Association presented a paper on the above subject in which they reviewed the work of the Association, discussed improvements, and indicated possible future trends, from which the following article has been abstracted.

ALTHOUGH the British Hot-Dip Galvanisers' Association was only formed about 18 months ago there is ample evidence that this organisation, whose aims are to promote better galvanising by co-operative research and increased efficiency, has been very successful. At its recent International Conference held at Copenhagen there was found an equally progressive attitude among many of the Continental galvanisers and the authors assured American galvanisers that the Association has every intention of playing its part in Western Union by co-operating as fully as possible with other European firms.

Statistics on Galvanising

In order to show the extent to which galvanising is carried on in Europe, a table is given which compares its use with that in other parts of the world. This table, which is reproduced below, shows the consumption of zinc for galvanising in some of the European countries in 1949, compared with U.S.A., Canada and Australia, some of which are estimates.

	Consumption of zinc for galvanising*	Total zinc consumed	% of total zinc used for galvanising	Consumption of steel in terms of crude ingot metal†	Lb. of zinc used for galvanising per ton of steel consumed	Lb. of zinc used for galvanising per head of population
U.K. ..	89,000	286,000	31	14,400,000	14	3¼
U.S.A. ..	311,000	628,000	50	64,100,000	11	5
France (including Saar)	15,000	105,000	14	8,300,000	4	¾
Italy ..	9,000	27,000	33	2,100,000	10	¾
Western Germany	16,000	97,000	17	8,400,000	4	¼
Australia ..	23,000	44,000	52	1,600,000	32	6¼
Canada ..	18,000	41,000	44	4,000,000	10	3
Holland ..	10,000	22,500	44	1,600,000	14	2¼

* Figures in long tons of 2,240 lb.
† If expressed in terms of finished steel, all the figures would be somewhat smaller.

The United States is the largest consumer of zinc for galvanising, and Britain comes next. But whereas our galvanising uses 14 lb. of zinc per ton of crude ingot steel, the American figure is 11 lb. of zinc per ton of steel, so that British steel consumers may be said to be more galvanising-minded. The same high ratio is found for Holland as for Britain. In Canada the galvanising and steel consuming industries are each twice the size of those of Italy, and they run U.S. close at 10 lb. of zinc per ton of crude steel. The most remarkable fact revealed in this table, however, is the high proportion of steel galvanised in Australia. The reason is that Australia supplies a very extensive home market with galvanised sheet, where it is almost a traditional building material, and also exports large quantities to neighbouring countries in the Far East.

The figures clearly show that the possibility of galvanising has not yet been realised to anything like the same extent in different countries: for example it is particularly surprising that France, where the process was invented, comes bottom on the list. It is also noteworthy that the four countries with annual steel consumptions of 4,000,000 tons or less produce a higher proportion of galvanised goods than France and Western Germany, with their much larger steel industries.

European Galvanising Methods

In Britain and on the Continent most general galvanisers use cold hydrochloric acid for pickling. Often no inhibitor is used, and frequently the need for controlling the composition of the pickle is overlooked. A few works use hot sulphuric acid, with a circulating system for continuously crystallising out ferrous sulphate, but the simplicity of cold hydrochloric acid is still generally preferred.

A distinction can be drawn between Britain and the Continent in fluxing. Following American practice, several of the largest general galvanisers in Britain have recently adopted the dry process, with a prefluxing dip in zinc ammonium chloride solution, though many general galvanisers are still dipping after simple pickling and drying, allowing the iron chloride to act as the flux. On the other hand, most galvanisers on the Continent use flux galvanising. In this process the work is pickled and then passes wet into the zinc bath through a layer of molten flux on its surface.

The Continental flux galvanisers make aluminium additions to their baths, but the metal is continuously lost by interaction with the flux. There is no doubt, however, that flux galvanising has advantages in reducing zinc ash formation, because the flux protects the hot zinc from the atmosphere. In consequence, a search has been made for fluxes which can be used on baths containing aluminium without causing the loss of aluminium in the form of volatile compounds. Some success has been claimed with cryolite fluxes, some of which are patented. Many Continental firms use these fluxes and development work is being done on them in England.

The rival claims of flux and dry galvanising are keenly disputed in Europe, but there is no doubt that each method has its real advantages, and which is better depends largely on the kind of work being galvanised. One drawback to the dry process is that it requires more space for the necessary washing and prefluxing vats and for a drying oven. Many European galvanising works are in cramped quarters in heavily built up areas, so there is no room for extra equipment. In some cases, where a changeover has been made, the works have been moved out to a new site.

Mechanisation

Dry galvanising, with its succession of dipping treatments, lends itself to mechanisation. Where long

runs of similar articles are being treated the plant can be fully automatic, with controlled dipping times. The best examples in Europe are at the works of the Crittall Manufacturing Company and of Henry Hope and Sons, both of which manufacture metal windows. The trend towards mechanisation is now spreading throughout the industry ; in an attempt to counteract high labour costs and the high price of handling, galvanisers are trying to improve the layout of their plant so as to simplify their operations. Some very well planned works have recently been built in Switzerland and Britain with this end in view, and others are still under construction.

The advantages of careful temperature regulation, preferably by means of a thermostat, are being more and more widely appreciated, and more attention is being given to bath heating. In Britain, for example, town gas is probably more generally used, because of its high calorific value and the precision with which its combustion can be controlled. In Switzerland, where electricity is the cheapest form of power, all the galvanising baths are electrically heated, by resistance heaters. There are also some electric baths in Sweden. One, a long bath with a sloping bottom, is heated from the top of the shallow end. A kind of electric blanket is in contact with a layer of graphite floating on the zinc, and the heat is carried to the deep working end of the bath by convection. This bath has been in use for 10 years ; it is drossed every six weeks. An induction heated bath is at present being built in another Swedish works.

Research and Development Work

Much of the research and development work has been concerned with dross and ash reduction, pickling inhibitors, fluxes, and aluminium additions. Large scale experiments, designed to measure the zinc efficiency of baths in everyday use, have been carried out and one of the most important facts revealed was that 50% of the zinc wasted in dross could be saved by proper washing after pickling, so that iron salts are not carried into the galvanising baths. In stating this figure, account has been taken of the fact that the galvanising processes tested also varied in other respects than the method of preparing the work. In fact, when the work was properly washed, about 12–13% of the total zinc consumed over a period formed dross, whereas without washing, the figure varied from 20–27%.

Since dross cannot be avoided altogether, it is important to see what can be done to recover useful zinc from it. So far it has only proved possible to recover about 25% of the weight of the dross as zinc which can be returned to the bath. This amount is only about one-half of the unalloyed zinc present in the dross. A Danish firm is working on an improved drossing and zinc recovery process, which has not yet been published, but it is stated that drosses containing 4·5–5% of iron have been obtained.

Work on similar lines has been done on the reduction of ash formation and on recovering zinc from ash, which is more important to galvanisers than its recovery from dross, because ash, which usually contains 70–90% metallic zinc, has a very low market value, owing to its contamination with chloride. Current work indicates that simple methods are effective, and lead to the recovery of 75% of the metallic zinc in the ash.

Not many European galvanisers use inhibitors, but they are now becoming more conscious of their value. A series of tests, is being carried out to compare the efficiency of different inhibitors for use with cold hydrochloric acid ; the effects of the initial additions have already been measured, and now the ageing qualities of the various inhibitors are being investigated.

All galvanisers are interested in the value of flux covers in reducing ash formation, and of aluminium in improving the ductility of the coating, and in the claims made for some fluxes that they do not remove aluminium from the bath. French and Swiss galvanisers make very heavy aluminium additions to their baths, which are flux-covered, and believe that the aluminium stays in the zinc, but results of examination of the fluxes used suggests that the beliefs are unfounded. Some of the special fluxes even appear to remove zinc quicker than a plain zinc ammonium chloride. However, the challenge to find a flux for use with aluminium has not been rejected, and the work goes on.

One piece of research of immediate interest is that concerning the addition of aluminium to galvanising baths. When heavy additions of aluminium (1½%) are made to a bath, it produces a galvanised coating in which the outer zinc is separated from the steel by an easily observable layer of ternary alloy. This alloy has good bending properties, and does not induce flaking of the coating, as do the iron/zinc alloys. With the usual small aluminium additions (about 0·10%), the alloy is probably still present, but it remains in a very thin layer which cannot be seen. It has been found that silicon enhances the effect of aluminium in preventing normal alloying.

The Future for European Galvanising

The statistics quoted earlier show that France and Western Germany, and to a smaller extent Italy, have much leeway to make up before their galvanising, judged by their steel consumption, matches that in Britain ; and much British steel still goes ungalvanised which ought to be dipped if capital equipment is to be made to yield the maximum profit. A case in point is railway rolling stock and permanent way accessories. Abroad, the Swiss and Austrian railways are using galvanised steel supports for overhead electricity supply equipment.

Another very promising field for extending the use of galvanising in Britain is that of gutters and rain water pipes. The great success of steel window frames, which looked like being a complete failure before it was decided to galvanise them, has shown our building trade the value of good quality galvanising. In the States the position is reversed, and galvanised rainwater goods are well known, whereas the galvanising of steel windows has hardly started. The only Continental countries using galvanised rainwater goods at all widely are Sweden and Switzerland.

Farmers all over the world, who are familiar with galvanised sheets and fencing and with galvanised cowstalls in milking sheds, would welcome similar treatment for much more of their equipment, which is often left out in the open, exposed to all weathers. The makers of the Land-Rover have taken a lead here and are having all its steel and cast iron fittings galvanised. The Rover Co. are anxious to resume galvanising the chassis when conditions allow it, as they are convinced that galvanising is the best protection for such steel work.

Grey Ironfounding Productivity Report

Conference on Technical Aspects

ORGANISED by the British Cast Iron Research Association, a Conference on the technical aspects of the Report, under the chairmanship of Mr. P. H. Wilson, O.B.E., was held at Ashorne Hill, Leamington Spa, on October 12th-13th. Although it had been expected that there would be a heavy demand for accommodation, the number of applications considerably exceeded expectations and many had to be refused. It has therefore, been arranged that a similar conference will be held on November 16th - 17th, at Ashorne Hill.

The subjects dealt with at the Conference included metallurgical aspects, sands and core practice, mechanical aids and transportation, moulding operations in relation to foundry lay-out, heating and ventilation, training and education of personnel, etc. This wide range of topics was introduced by members of the Team who were also available to answer questions on American practice. The members of the team present, representing management, technicians, and operatives, were S. H. Russell (Team Leader), H. T. Angus, C. Blackburn, N. Charlton, H. B. Farmer, H. Hendy, G. B. Judd (Team Secretary), A. Kirkham, W. R. Marsland, M. Martin, G. W. Nicholls, W. B. Parkes, E. J. Ross, and J. Stewart.

In the following account an attempt has been made to deal with a number of points arising in the Report itself and in the discussion at the Conference.

Buildings

On the whole, little difference was noted in the foundry buildings, although several modern shops have extensive basement accommodation for storing, sand mixing and access to shake-out mechanisms. In a number of instances, the foundry forms one bay whilst an adjacent bay, of equal height, has two floors, the upper one being used for core-making; the cores are dried in a continuous vertical stove discharging at foundry level. Cleanliness and the use of sandcutters are facilitated by the provision of concrete floors in many foundries.

The extremes of temperature encountered in the U.S.A. complicate the problems of heating and ventilation. While many foundries have excellent heating systems, which also permit cold air to be supplied in hot weather, 20% of the foundries seen had nothing but coke braziers for heating. Portable fans, capable of blowing hot or cold air, are used at strategic positions and local ventilation schemes are operated at sand handling plants, pouring stations, knock-out stations and fettling shops. In the larger foundries, the removal of cores by high pressure water blast eliminates the most important source of dust. The use of a portable vacuum cleaner for floorsweeping was queried on the grounds of safety in view of the fact that the finer dust would pass through the bag of the machine. Washing and locker accommodation were provided in varying degrees at all the foundries visited.

Sand Practice

The three main points noted in connection with the sand mixtures used in America concern the use of hardwood flour in facing sands (to prevent scabbing in flat-topped castings), the use of pitch in skin dried moulds, and the close sand control exercised. Silica or naturally bonded sands of the required permeability are freely available, and suppliers appear to be more willing to treat them at the pit to produce the type wanted by the particular foundry. More foundries use synthetic sands than in Britain, but this seems to be governed by the method of moulding, natural sand being preferred for hand moulding. Bentonite, which is comparatively cheap, is widely used as a binder, and coal dust is used in much the same proportions as in Britain.

The main difference in dry-sand practice is the much greater use of skin drying, facilitated by the addition of pitch to prevent both cracking during drying, and the subsequent reabsorption of moisture. The use of pitch is almost entirely confined to dry sand, in contrast to British practice where it is more widely used with green sand. Skin drying is effected by charcoal trays or by tunnel-type hot-air driers. Where the numbers of castings made in moulds containing pitch is small, no handling precautions are taken, but in one large foundry using pitch extensively, the man responsible for unloading wears protective clothing preventing contact between his skin and the pitch and also inhalation of the dust. The danger from pitch dust can be greatly reduced by using a grade known as "pelleted pitch." Unless care is taken to exhaust the fumes given off during pouring, the effect on the foundry atmosphere will be bad. The difficulty of blacking a mould containing pitch can be overcome by the use of a wetting agent, although it was observed that no blacking was used in many cases. The knock-out sand needs longer milling to take up the required moisture again, but no trouble seems to be experienced in sand containing pitch being scrapped due to balling up in the mill.

The differences in oil sand practice observed were mostly of a minor character. Little or no use is made of synthetic resins and a cereal binder is used with a thin oil in most foundries. The main difference lies in the use of iron oxide to reduce metal penetration.

Reference has already been made to the extensive use of sand control. Several foundries have no chemical laboratory, but almost all exercise sand control. The almost universal use of testing equipment made by a single manufacturer, who runs courses of instruction in its operation, leads to a greater uniformity of results throughout the country. Great importance is attached to moisture content, particularly of facing sands. In many foundries, in addition to laboratory tests, frequent checks are made by the mill operator with a "Speedy" moisture tester. One foundry, whose return sand is dry but variable in temperature, is working out the relation between temperature and volume of water required to give a constant moisture content.

Waterproof silica flour is frequently used for facing sand and there appear to be no safety regulations in force concerning this matter.

Most foundries have space for storing sand for several weeks' working, owing to the impossibility of working the quarries during the exceptionally cold spells. Sand

is usually delivered in wagons of 50 tons capacity, the type of wagon being specified by the foundry to suit the particular sand and the method of unloading. The sand handling equipment is designed to eliminate manual handling, as far as possible, and use is made of conveyors, clam-shell grabs, elevators, silos and wheeled shovels. Most of the sand-mixing machinery used is well known here, from the barrow and pan mullers to the multiple intensive mixers with automatic devices for measuring sand, water, etc. The sand-cutter is in general use for reconditioning of floor sand, when sand conveyor systems are not installed, and usually operates at night.

Metallurgical Aspects and Melting Practice

All American foundries are very user-conscious and in mass production engineering, occasional hard castings can have very serious effects on the smooth running of the production lines. It is regarded as a major calamity to produce occasional castings of low machinability as it may easily lead to the loss of a repeat order. This importance of machinability results in the foundries supplying the softest iron which will do the job. The main difference in materials is the lower phosphorus content (usually $< 0{\cdot}6\%$) of the pig iron. Although we can make pressure-tight castings in high phosphorus irons, it is necessary to take precautions which are not conducive to fast working, and the Americans use irons of $0{\cdot}2$ or $0{\cdot}15\%$ P. for this purpose. The low phosphorus figures for the irons in general use mean that there is less risk of hard castings, and the shock resistance is better for a given tensile strength. The bulk of iron castings produced in the U.S.A. are of 13–15 tons/sq. in. U.T.S., with only a small production above 18 tons/sq. in.

Any saving of time and labour in handling raw materials results in cheaper castings and greater output. Electro-magnets are widely used for unloading and handling pig and scrap, and considerable skill is displayed by the operators in weighing out charges by these means. Coke, also, is often loaded into hoppers for loading into the cupola charging skips, but in some instances, the poor mechanical properties of the coke have resulted in a reversion to hand methods of handling

In general, the amount of metal melted per day per foundry is higher than in Britain and, consequently, more attention has been devoted to the development of mechanical cupola chargers. These are usually of the drop-bottom skip type, with variations in design to suit the individual foundry's requirements. Cupolas are usually of the drop-bottom type of Whiting design, with a tendency to have a large shell diameter lined down to the required size. This gives a reserve of melting capacity should the need arise and may account for the higher tuyere-area/cupola diameter ratios used. The charges are similar to British practice with the exception of coke, which tends to be heavier, due to the soft nature and high ash and sulphur contents of American coke. Intermittent and continuous tapping sytems are used with, in a few cases, gas or oil-fired receivers. Slag is disposed of by running on to the floor, into ladles, or into a water-tank from which it is removed by bucket elevator. The use of a " Bondactor," a device for spraying patching material on to the lining, has been found to save its cost in a few months. A few hot-blast cupolas were seen but the B.C.I.R.A. is of the opinion that hot-blast is only worthwhile with melts of at least eight hours, where the coke quality is low. Dust suppressors are fitted on some cupolas, and in some states dust counts are taken.

The usual practice is to melt one grade of metal only and to adjust for different jobs by ladle additions. In one plant a duplex process, in which one-third of the total melt is passed through an electric furnace, gives a very flexible set-up. The molten metal is handled efficiently using mono-rail runways, transfer trucks and a plentiful supply of ladles, often of the barrel type. For pouring, devices are in use to permit of the operation being carried out by one man.

Moulding and Coremaking

There is no fundamental difference in moulding and coremaking practice between the U.S.A. and Britain; the essential difference lies in the American policy of using mechanical methods wherever possible, and of making every effort to economise in the use of skilled labour by ensuring that the skilled men are efficiently served with everything they require.

One of the factors emphasised by the Team is the high quality of the pattern equipment, which is usually made by specialist firms. Apart from its excellent quality, considerable thought is given to the subsequent handling in the original making of the pattern. Great care is taken of patterns and vibrators are frequently attached to loosen the pattern before withdrawal from the mould. Almost all small machine-moulded castings are produced from double-sided pressure-cast aluminium match plates, and the runner system is usually incorporated in the equipment.

The most outstanding feature in the production of light castings is the " pop-off " type of taper flask, which is precision-made and capable of very high outputs. The use of taper flasks greatly simplifies knock-out and eliminates the necessity for returning empty moulding boxes to the machine moulder. Capital costs are also substantially reduced. Various types of pneumatic moulding machines are used and all are adequately air powered, although of light construction. A number of power and train conveyor systems were seen and are described in the Report.

For medium castings with short runs, hand moulding in wooden boxes may be employed, while shallow frame castings may be made in hinged moulding boxes from plate patterns. For long runs, moulds are made from pattern plates on jolt roll-over machines. Sand slingers of the fixed or loose tractive type are also used in jobbing foundries using loose patterns, and it is common practice for a mould to be rammed in one section of the foundry and then transferred to another, where pattern withdrawal, finishing, coring and closing are done by skilled moulders.

Mechanical equipment is used in certain instances for the manufacture of castings of 5–6 tons weight, including sandslingers and pnuematic rammers. Loam moulding is not extensively practised but turbine cylinder moulds were seen being made in this way.

The corebox equipment used is stouter and of a better finish than that used in British foundries, and metal inserts in wooden boxes, and even metal boxes, are used where quantities are large. The methods are similar to those in operation here, but greater output is achieved by the efforts of the workers backed up by mechanical aids, the use of simple gadgets, and efficient servicing. A number of points of interest are mentioned in the Report, together with descriptions of core-drying ovens. Control of core sand is achieved by accurate measurement of sand (which is of consistent quality) and

binders. For large cores, sandslingers fitted with a guide tube on the slinger head may be used.

Miscellaneous Equipment and Power

Reference has already been made to some of the mechanical aids used to speed-up the various operations. In addition to these, considerable use is made of hand and power operated devices in transportation. The use of the wheelbarrow is not disdained, and large numbers of well designed barrows are available, including a motorised wheelbarrow having a carrying capacity of 1,000 lb. Powered lift trucks are in part being replaced by fork lift trucks, which have many advantages, especially when stacking is required. Although fork lift trucks are available here they are usually too large to be suitable for use in small foundries. Appreciable use is also made of sand dumpers and mobile cranes.

For overhead handling, the normal types of jib and gantry cranes are available but the most striking features seen were the mono-rail systems and "latching cranes" installed in many of the foundries visited. The mono-rail systems cover most of the lifting points in the foundry and have manually operated switch points and turntables; the rail itself is of extremely light construction. The "latching crane" is a light gantry crane with four wheels to each carriage so as to bridge gaps in the gantry where mono-rails run at right angles. The bridge girder of these cranes is slung beneath the carriages and extends beyond the gantry rails to link up with other cranes and mono-rails, thus enabling loads to be diverted over large areas without lowering. Ingenious load transfer devices enable floor transport to be used in conjunction with overhead equipment.

Where the area served is limited, use is made of compressed air for lifting purposes, thus enabling a wide range of working speeds to be obtained.

Throughout, there appeared to be rather more equipment available than we should consider necessary, but this is undoubtedly connected with relative costs of labour and equipment. Most of the equipment used demands ample power and about twice as much electricity is used per ton of iron produced as in comparable British foundries. Coal as a fuel is being replaced by gas and oil, and it is interesting to note that considerable use is made of a natural gas piped from Texas.

Education

The whole of the school and college environment and training in the U.S.A. tends to produce men who are versatile and co-operative, while retaining a high degree of individuality. Courses appear to be essentially practical, and mechanical ability and ingenuity are encouraged from the early stages. The result is to produce workers who expect and do not resent increased mechanisation, supervisory staff who are anxious to improve the output of their department by every mechanical means, and administrative heads who encourage inventive talent and provide adequate support for innovations suggested by their staff. Considerable encouragement is given to employees to improve themselves by internal and external training schemes, and internal courses for foremen and managers, dealing with costs, labour relations, etc., are common. University curricula tend to extend beyond the main subject and to cover such subjects as accountancy, business management and psychology. The practical nature of the university training results in little or no resistance to the employment of graduates on the grounds that they are too academic, but it should be noted that university students expect to enter industry at workshop levels and to gain their promotion on merit.

Management Planning and Costing

In the American system, it is possible to start as a floor sweeper and work one's way up to the position of manager. Many foundry managers have followed this course and the result is that they have a very good knowledge of the workers' problems, which makes for better relations between management and men. The American manager is always a good business man and has sufficient technical knowledge to make him an efficient executive. He believes that profit making is the measure of success and there is no resentment from the workers who realise that they cannot prosper unless the firm does.

There seems to be a general opinion that a firm cannot do without spending a lot of money on equipment, and that it is essential to be fully equipped to take advantage of any boom period. There is no fear of taking appreciable risks if it is concluded that, in the long run, it will be to the mutual benefit of all concerned.

Considerable attention is paid to planning and costing, and it is usual for every aspect of production to be considered carefully before a job ever reaches the shop floor, so that snags can be avoided. Almost every foundry has a simple costing system which, although it may not be strictly accurate, is sufficiently so to be effective, and has the merit of being understood by all concerned. All foremen and shop executives are very cost conscious and are fully acquainted with the costs of their own section. It is not uncommon for costs to be discussed at local costs groups where other firms' costs (given under code numbers) can be compared; in this way inefficiencies are disclosed. In spite of the foregoing, an outstanding feature of the plants seen was a lack of elaborate production planning and of progress control systems needing a multitude of forms.

The ability and energy of the average foundry foreman greatly impressed the members of the Team. The management trains promoted men, who may be unskilled men, skilled men, or college graduates with at least two years shop floor experience. Reference has been made to internal training schemes, and there are also adequate facilities available for the training of foremen and managers in Foundry Educational Foundations. The fullest possible information concerning his section is available to the foreman, who has a detailed knowledge of the operations in his section and a good general knowledge of the working of the foundry as a whole. Payment is on a bonus system and the Team emphasises the importance of the foreman being paid substantially more than the workers he supervises. It is also noted that the foreman's job is to supervise and keep production moving rather than to busy his head in particular problems.

In the limited space at our disposal, any attempt to cover the Report and the Conference must inevitably leave many gaps. To those who would be glad of more detailed information on technical and other aspects of American productivity, a study of the Report is strongly recommended.

A Film on Hard Metal

HARD metal in one form or another is so much a part of modern engineering that a colour sound film produced under that title has more than ordinary interest. Such a film was screened at a recent preview given at the Hammer Theatre, Wardour Street, London, W.1 and those privileged to see it found the subject presented in a most instructive manner. The colour sound film which runs for approximately 45 minutes, shows in vivid detail some of the manufacturing processes involved in the quantity production of tungsten carbide and a number of examples of this useful material at work in industry.

The producers of this 16 mm. film are Murex Ltd., who presented it on behalf of their subsidiary company Protolite Ltd., and, since they are producers of hard metal from the basic ores to the final products, they are in a unique position to give the graphic presentation of all the chemical and mechanical processes involved in the production of this increasingly important material which is distributed under the trade name "Prolite" by Protolite, Ltd. We are sure this film will be in great demand and those wishing to borrow it should make early application to Protolite, Ltd., Central House, Upper Woburn Place, London, W.C.1.

Recovery of Ferrous and Non-ferrous Scrap from London's Trams

THE widely reported "burning of London's trams," which began at Charlton recently is not the wasteful process it might appear to be; it is, in fact, permitting the recovery of thousands of tons of badly needed iron and steel scrap, and hundreds of tons of non-ferrous scrap, for re-use in industry.

The Raw Materials Division of George Cohen Sons and Company Ltd., has recently purchased some 700 trams and undertaken to demolish them at a special depot—which has been referred to as a "Tramatorium"—where they are fired to remove the wood. Burning the trams might seem a waste of wood, but the value of such material recovered by careful dismantling would fall far short of the cost of the time and labour involved.

Before firing the tram bodies, however, considerable quantities of plate glass, various electrical fittings, brasswork, seats, doors, etc. are salvaged for sale. After the burning, ferrous and other metal parts of the superstructure are easily removable; but the greater part of the iron and steel scrap is derived from the chassis bogies—two from each tram—and motors. The electrical gear yields copper and other non-ferrous metal. Sorting and grading of most of the various types of scrap is being carried out on the spot. The various grades of steel are separated, most of which is consigned to South Wales. The light iron is compressed into "briquettes" suitable for use as scrap in steel furnaces; and the cast iron will be despatched to foundries for re-melting.

Burning of London Trams

Pumping Under Impossible Conditions

THE accompanying illustration is an action photograph of a Girdlestone glandless diaphragm pump circulating vitreous enamel. In spite of the severity of the conditions, the Girdlestone pump shown is performing regular duties without trouble or attention. This particular pump was developed specially for use in industries where corrosive and abrasive liquids have to be pumped. It will handle a wide range of liquids from hydrochloric acid to solutions containing diamond dust and ground glass.

The liquid is completely sealed in the pump and all points subject to leakage, such as stuffing boxes, rotary seals, etc., have been eliminated. Fuller particulars, together with an "explosion" drawing of the pump and detailed specification, is available from Girdlestone Pumps Ltd., 23-25, Davies Street, London, W.1.

Pumping vitreous enamel with a Girdlestone pump

Production Engineering Research Association

Its Growing Importance to Industry

By Dr. D. F. Galloway, Wh.Sch., M.I.Mech.E., M.I.Prod.E., A.M.I.E.E. B.Sc.Hons., M.Inst.Pet.

The object of this Association is not merely to carry out research or to collect and correlate information, but to ensure the effective application in industry of data which will assist in the improvement of efficiency and economy throughout the whole range of production activity. This report indicates the manner in which this objective is being achieved.

IN the period since the last survey of the work of the Production Engineering Research Association appeared in this journal in October 1949, there has been a rapid expansion of all the Association's activities, and a consolidation of the progress made in earlier years. A number of investigations have been completed, and others are nearing completion, but the field of production engineering research still awaiting attention is extremely large and plans are already complete to further extend all phases of the Association's work as rapidly as possible. As the Association's membership and income increase steadily, new workshops and laboratories are being secured to investigate many of industry's most urgent practical production problems.

The Association's growing importance to industry has been repeatedly stressed by independent observers during the past year. For example, Mr. Austen Albu, M.P. for Edmonton, and a qualified production engineer, when speaking during the recent House of Commons debate on the utilisation of Britain's scientific resources, stated :

" I should particularly like to draw attention to the establishment, three years ago, of the Production Engineering Research Association as one of the industrial research associations supported by the D.S.I.R. Since it was founded it has reached a membership of 250 firms and it believes that its total possible membership is 5,000. It has a staff which has grown from 11 to 100, and it aims at a staff of 1,000. Its charter covers research into practically all the methods of converting raw materials into finished products except perhaps in the chemical and textile industries. I suggest that this body, which is one of the first bodies concerned with manufacturing methods in general and with manufacturing problems, particularly in the engineering industry, is worthy of the very fullest support."

Membership

Membership of the Association has increased by 20% to a total of 260 during the past year. This represents an important advance in PERA's capacity to undertake research, but efforts to expand the membership and income of the Association will continue in order that the economic benefits of researches and services can be made available on an increasing scale.

The Association has always extended an open invitation to directors and production personnel from all non-member firms to visit Staveley Lodge to see for themselves the facilities and services available, and this has been one of the most important factors in promoting its growth.

View in PERA workshops showing a young engineer (left) from a member firm, investigating press tool blanking and stripping forces. The measuring elements are built into the die-set, and the instrument box with cathode ray oscillograph and camera are shown at the side

Considerable interest in the Association has been evoked at meetings of prominent industrialists held in various centres throughout Great Britain. The most important of these meetings took place at the Institution of Mechanical Engineers last December, when Sir Claude Gibb, Chairman and Managing Director of C. A. Parsons & Co. Ltd., addressed directors and executives of engineering firms who attended at Sir Claude's invitation to learn about the work and aims of PERA. In a widely reported speech Sir Claude stated :

" It may be considered that nothing short of major re-equipment of factories will give us the desperately needed increase in productivity. Whilst it is true that much is needed in that direction, there is so much that can be done with reasonably efficient existing equipment that I am certain our best hopes lie in tuning-up existing plant as our short-term plan, whilst proceeding with re-equipment as the long-term attack.

The problem is to secure this essential tuning-up of existing equipment in the shortest possible time and at a minimum cost to industry. The majority of industry cannot, however, afford the expense of a

Investigations in progress into life and performance of a wide range of taps from various suppliers. Nut blanks are fed automatically to a tapping dynamometer (centre) at a rate of up to 1,000 per hour. Tapping forces are recorded by the Talymin (left).

large efficiency and research staff, and it was because of this that the Production Engineering Research Association was born. The object of the Association is not merely to carry out research or to collect and correlate existing information, but to ensure the effective application in industry of data which will assist in the improvement of efficiency and economy throughout the whole range of production activity. Pera research and information services are essentially practical and deal with day-to-day problems.

I commend the Association as a means of tackling immediately those aspects of production efficiency within our control. It is a truly co-operative effort and, as such, is of vital interest to us all."

Industrial Control of Pera's Activities

To ensure that the research programme is as closely related to industrial requirements as possible, and to facilitate application of the most recent knowledge and industrial experience to all branches of the Association's work, the Technical Committee structure has been modified recently. The former Technical Committee, consisting of representatives nominated by member-firms, has been renamed the Technical Policy Committee, and separate Technical Committees, also composed of member's representatives, have been established for each field of research. Advisory Panels representing various sections of industry are now being formed to discuss particular industries' production problems and will meet regularly to recommend subjects requiring research to the various Technical Committees.

Among the first Advisory Panels to be formed are the Road Vehicle and Accessory Manufacturer's Advisory Panel, and those for Agricultural and Earth Working Equipment Manufacturers, Electrical Equipment Manufacturers, and Engine and Turbine Manufacturers. The Road Vehicle and Accessory Manufacturers' Advisory Panel is as follows :

Messrs. H. N. Whitehouse, Austin Motor Co. Ltd. ; J. Silver, Jaguar Cars Ltd. ; J. Harris, Standard Motor Co., Ltd. ; L. H. Sewell, A.E.C. Ltd. ; D. L. Campbell, Albion Motors, Ltd. ; E. W. Hancock, Humber, Ltd. ; G. Murray, Pressed Steel Co., Ltd. ; A. Hosker, Leyland Motors, Ltd. ; A. T. Cheesley, Metropolitan-Cammell Carriage & Wagon Co., Ltd. ; A. E. Hudson, Westinghouse Brake & Signal Co., Ltd. ; T. Bissel, J. B. Brooks & Co., Ltd. ; B. Stevenson, Marcroft Wagons, Ltd. ; C. F. Cunningham, Projectile & Engineering Co., Ltd. ; A. Thomas, Bromilow & Edwards Ltd. ; J. Percival, Fisher & Ludlow Ltd. ; S. H. Beer, Aveling-Barford Ltd. ; E. Carrington, Ford Motor Co., Ltd.

Information Department

The very heavy demands made on all information services during the year has necessitated a substantial increase in Information Department staff. In answering more than 600 technical enquiries in the period under review, Pera has analysed and correlated existing information on many aspects of production engineering and has carried out special investigations to assist members in overcoming a variety of practical workshop problems. Although this work has been undertaken specifically for the benefit of individual firms, it has often brought to light information of value to other members and this is being made available to members generally.

Problems which have been dealt with embrace almost every branch of production engineering and include, for example, the elimination of surface porosity in zinc pressure die-casting, colour schemes for workshops, the manufacture of many types of product, induction heating techniques of brazing and core-drying, incentive schemes, casting of thin sections, lubricants for drawing operations, location of suppliers of machines, equipment and materials, etc.

Many of the enquiries have been answered by reference to existing information contained in the Association's library, and the various national libraries to which it has access, in the form of books, periodicals, trade literature, and reports issued by research stations, professional societies and universities. Typical of these enquiries were the requests for bibliographies on industrial costing, and one on planned maintenance of engineering plant. Another example related to information on poisoning by metals, indicating for each of the principal poisonous metals, the frequency and severity of poisoning, the way in which poisoning occurs and the principal organism affected. Extensive use has also been made of PERA's rapidly expanding production engineering library in advising firms on such subjects as mechanical handling, factory organisation, workshop layout, pressing and spinning of metals, forging, impact extrusion, etc.

Some enquiries have been speedily answered by enlisting the specialisedk nowledge of members of PERA staff. Enquiries have been regularly received on such fundamental aspects of metal machining as the magnitude of cutting forces, cutting angles, speeds, feeds, etc., and in preparing replies it has been possible to draw not only on published information but on knowledge gained from researches conducted in PERA workshops.

When it has been found impossible to answer a technical enquiry by reference to existing information, practical work has been undertaken by the Association when it was considered that the problem would provide a solution of general interest, or which would assist other members with similar problems. Routine practical work such as surface finish analysis and measurement of cutting forces during machining operations, etc., has also been performed for members.

PERA Bulletin

The Association's Bulletin is playing an increasingly important part in the dissemination of production engineering knowledge, largely as a result of the much wider distribution achieved in member-firms during the past year. This monthly Bulletin now has a circulation of about 6,000, ensuring that information published in British and foreign periodicals on all production processes is made easily available to executives, planning and design staff and workshop personnel in each company.

Over 2,500 abstracts were printed in the Bulletin during the past year and 15,000 reprints and copies of production engineering articles and papers were sent to member-firms.

PERA Student Scheme

The first course of training in production engineering development held at the Association's Melton Mowbray headquarters was completed in October last year. The courses were started at the request of member-firms to provide an opportunity for their most successful young engineers to acquire a really progressive outlook on all aspects of production, including even the most firmly established practices.

Each course includes practical experience with PERA research teams, talks and discussions with senior engineers, and works visits to illustrate the manufacture of widely different products. The main objective of the scheme is to encourage an analytical yet practical approach to everyday production problems and general improvement of production methods. This is achieved principally through the young engineer's participation in actual research work rather than organised instruction. Nevertheless, formal instruction and discussion are valuable but not major parts of the course.

Each engineer is attached to a research team investigating metal cutting, presswork or machine tool performance, and other subjects are being added to the list as the Association's range of activities are extended. Experience of two courses has confirmed the belief that six months is required, on average, to thoroughly grasp the general principles of production engineering research. For this reason the engineer usually remains with the same research team throughout the course.

To assist participants in getting maximum advantage from the facilities at the Association's headquarters, and in acquiring a knowledge of its activities outside those on which they are engaged, lectures are given by senior members of its staff. Talks on metal cutting, presswork, utilisation of machines, standardisation, cutting fluids, the use of statistical methods in research, surface finish and other branches of production engineering are given and are followed by discussions on the application of research in these fields.

The practical experience gained by participants in the Scheme can best be illustrated by a brief review of actual work done.

Engineers attached to the metal cutting research section participated in tests on: Drilling, reaming, and tapping characteristics of six materials; effect of core hole size on tapping torque; tap, die-head, and reamer life tests with high tensile steels; variation of screwing forces with different dies on a range of materials; and effect of different soluble cutting oils on cylindrical grinding efficiency.

Students in the machine tool section conducted surface table flatness tests, lathe power-absorption tests, and also assisted in the following radial drilling machine tests: Spindle bearing temperature tests; efficiency tests on drill head and arm-elevating motors; arm elevation and drill head power tests; efficiency tests on drill head and motor at various speeds and loads; dynamic and static deflection tests; determination of metal removal rate per horsepower-hour when drilling with different diameter drills; and complete alignment test of machine.

Students in the metal forming section took part in such tests as: Erichsen cupping tests on various materials used in a blanking investigation; measurement of press tool blanking and stripping forces; metallurgical examination of sheet materials used in press-working research; and measurement of thread rolling pressures.

Experience in designing and calibrating special measuring equipment and tools used in production engineering research is another valuable feature of the course. Special equipment designed and calibrated by students includes: Hydraulic loading device for power press deflection tests; special press tool with a device for measuring blanking and stripping forces; and dynamometer for measuring thread rolling pressures.

All students visited firms manufacturing electric lamps, motor vehicles, machine tools, cutting tools, agricultural machinery, internal combustion engines, iron and steel plants, and typewriters.

The main object of the Student Scheme is not to provide the young engineer with what must be a relatively narrow range of facts relating to one aspect of production engineering but to broaden his outlook and provide him with a background of fundamental knowledge which can be brought into use in dealing with any of the varied and often complex problems associated with manufacture.

Courses and Conferences

The Student Scheme is part of a wider educational objective to assist each member-firm to secure maximum benefits from membership of the Association. Special training courses were held at Staveley Lodge from time to time during the past year. Courses of this type are among the most effective means of securing the prompt

Two PERA students receiving guidance from a member of PERA staff on the planning of an investigation. Experience of planning research is as important as actual participation in practical work

application of research results on the widest scale in member-firms, and developments in the character and scale of training courses are taking place continually. Courses held in the last twelve months have varied in duration between one day and three months, and have been devoted to various branches of production engineering.

The demand for and value of training courses has been amply confirmed during experimental refresher courses for foremen, supervisors and managers recently held at Staveley Lodge. The success of these courses encouraged the Association to introduce a new series of refresher courses, consisting mainly of talks and demonstrations, beginning in September. In these courses the results of recent research are presented in a form which facilitates their application in member-firms, and practical demonstrations of research in progress have been designed to secure the application of the results of research as they become available.

The illustrated talk entitled " Know More About the Machines You Use " for the first series of refresher courses deals with the practical significance of PERA's researches into the performance and utilisation of machine tools. Suggestions are made, for example, on precautions necessary for the production of accurate work, and the causes of chatter and vibration are examined. Changes in power consumption under various conditions, the significance of rate of metal removal, and the performance of bearings and drives are demonstrated by means of research results. Important aspects of the installation and maintenance of machine tools are dealt with in particular relation to recently established information on machine tool performance.

An informal discussion in which the audience takes part follows the talk. Discussions during the experimental refresher courses showed clearly that industry still urgently requires answers to many questions of machine tool performance and development.

After the discussion visitors are free to make their own way around a series of about twenty demonstrations in the Association's workshop and laboratories relating to different aspects of investigations now being carried out on machining and presswork techniques, and also demonstrating some of the features of machine tool performance discussed in the talk.

The demonstrations of practical work include: Determination of bend allowances for various sheet metals to reduce the amount of trial and error in producing blanks of the correct size; investigations of the effect of different clearances between punch and die, and the influence of variations in punch speed on punch load and stripping force; research into the effect of tool grinding, speeds, feeds, etc., on tool performance; mechanised research on the performance of various taps when tapping stainless steel and other materials; comparison of cutting fluids for specific machining operations.

The refresher courses are a general development of the scheme whereby any member-firm can send groups of foremen to Staveley Lodge for instruction in a chosen subject.

In one of the new buildings now being erected at the Association's headquarters, a centralised tool and cutter grinding section is being established in order that shop personnel from member-firms can be trained in the most up-to-date cutting tool grinding techniques as each stage of its metal cutting research programme is completed.

Member Liaison

Member liaison visits at an average rate of about two per year have been made to firms during the period under review. These visits have been of considerable assistance not only in making known the services available, but in acquainting the Association with the practical problems awaiting solution in member-firms. A mobile team of senior engineers has also been at constant readiness to visit members at short notice to deal with a difficulty on the spot, or to bring the problem back to Staveley Lodge for immediate investigation.

A large volume of practical work has been undertaken in the Association's workshops and laboratories on behalf of individual members as a result of liaison visits. Financial savings amounting to thousands of pounds have been achieved in some member-firms as a result of these practical investigations.

Research Programme

A number of general and private researches have been completed during the year, and reports issued to members. The demand for research reports has been very heavy with the result that some are being reprinted.

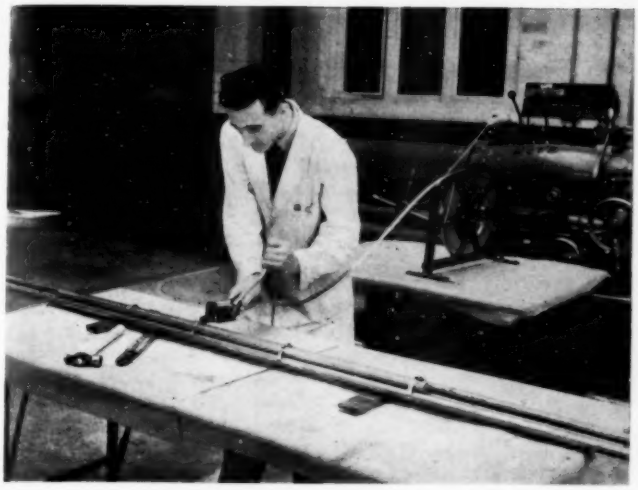
Following an investigation of the physical and chemical properties of representative commercial soluble cutting oils in general use, tests were carried out to determine the effect of the oils on the efficiency of turning, milling, drilling and grinding operations.

Tests to compare the effect of soluble cutting oils on the life of cemented carbide and high-speed steel lathe tools, when turning various materials, revealed considerable differences in tool life when using different fluids. In tests with cemented carbide tools, one soluble cutting oil consistently gave a tool life greater than or equal to that obtained with another oil costing 120% more.

Even wider variations in performance were observed during PERA's investigations into soluble cutting oils for drilling. Drill life was in some cases more than double that obtained with other oils. In view of the widely differing dilutions recommended by soluble oil makers, all machining tests were conducted at a dilution of 1 : 25 as well as at the makers' recommended dilution, and this gave interesting results. For instance, when drilling several types of steel one oil consistently gave lower drill life with weaker emulsions. The use of weaker emulsions may, however, be accompanied by greater risk of corrosion damage to machine tool surfaces, and the results of an extensive series of corrosion tests made by the Association will further assist industry in selecting the best soluble cutting oils for particular applications, especially when deciding between oils of comparable cost and performance.

The corrosion tests consisted of placing samples, mixed with metal chips, of all the emulsions tested on specially prepared plates made from cast iron used by different machine tool makers. Considerable differences in corrosion were observed with various soluble oils, indicating that careful selection is necessary to avoid damage to machine tools.

An investigation is now being carried out into the performance of a number of experimental aqueous cutting fluids containing various additives and rust inhibitors.



A special investigation in progress, to determine the suitability of a strapping machine for a specific packing problem.

Tapping Research

An extensive investigation is being made of the life, performance and geometrical characteristics of a wide range of taps. Other tests are being carried out to determine the effect of core hole diameter on tapping torque and strength of threads. These tests are being carried out in conjunction with the National Physical Laboratory.

Preliminary tests have shown that differences in tap design result in large differences in tapping torque. Large differences in tap life can be expected between similar taps supplied for the same purpose. During the course of these and other tapping tests being performed by the Association, a study is being made of the fundamental aspects of tapping, and it is expected that formulae will be developed for calculating tapping torque for various materials and different sizes of taps.

Results of tests to determine the effect of core hole diameter on tapping torque and strength of thread should especially interest those industries, such as the aircraft industry, in which designers often specify tapped holes with a depth of thread between 80% and 100%. Approximately half a million holes will be tapped during the course of the tests, and more than 10,000 tap measurements will be made.

The opportunity has been taken in this investigation of carrying out tests on nuts which will be subsequently supplied to a member-firm.

Drilling Investigations

Investigations are in progress into the performance of drills and the drilling characteristics of various materials. Previous research has shown that the method and accuracy of drill point grinding have an important influence on drill life, and a correctly ground drill may drill five times as many holes as an incorrectly ground drill.

In many workshops unsuitable combinations of speeds and feeds lead to frequent drill breakage, and tests are now being conducted to establish the correct cutting conditions for a range of small drills. Special equipment is being developed to test small drills supplied by British and foreign makers.

Demonstrations of pressworking research during a recent refresher course for foremen at Staveley Lodge.

Grinding Research

Tests have already shown that correct selection of cutting fluids leads to big improvements in grinding wheel life and loading, and in the surface finish of ground components. Wheel life and workpiece finish are also affected by wheel dressing, and tests are to be made to find the most suitable rates of wheel dressing for maximum wheel life. Related tests will determine optimum transverse and in-feed rates of the diamond during wheel dressing.

Tool grinding greatly affects the life of lathe tools and tests now being carried out will determine the effect of tool finish on tool life during rough turning, and surface finish of workpiece and tool life during finish turning. These tests are being made with tungsten carbide, high-speed steel, and Stellite tools.

Metal Forming Investigations

Several metal forming researches have been completed during the past year. These include an investigation into the effect on bend allowances for 90° bends in mild steel, stainless steel, and aluminium alloy, of such factors as material analysis and condition, directional properties of the sheet and variations in material thickness. Formulae based on the results of a large number of tests enable bend allowances to be calculated sufficiently accurate for all practical purposes, and thus make possible the computation of blank sizes from component drawings, as well as allowing the manufacture of dies and forming tools to proceed simultaneously. Bend allowances for brass, copper, mild steel, alloy steel, and aluminium in thickness of sheet up to $\frac{5}{32}$ in. are being established in another investigation.

Researches are being carried out into the effect of different amounts of die clearance on resultant hole shape, size, finish, etc., and on punch load and stripping

force for a range of materials, which are now nearing completion. An extension of this work has recently been authorised in order that punch load, stripping force, and the relationship between area of sheared edge and punch load may be determined for a wide range of materials of different thicknesses when using varying punch and die clearances and punch speeds.

Research into the formability of various materials has been carried out on behalf of the Ministry of Supply. It is expected that the research report which has been prepared will in due course be released for circulation to members. The Ministry is now giving consideration to a further programme of investigations to continue this work.

Equipment is being designed for an investigation of the relative merits of a number of lubricants for deep drawing operations. It is also proposed that a programme of research be initiated on impact extrusion, and the programme for this work will be compiled shortly.

Machine Tool Investigations

General investigations of several types of machine tools, such as lathes, drilling machines, milling machines, etc., have been completed or are in progress. These investigations have been designed to assist machine tool users in the selection, efficient utilisation and economic maintenance of machine tools, and afford guidance to makers in the design and construction of their machines.

Machine tool research includes investigations of a machine's accuracy, rigidity, and efficiency, and also of its performance in roughing and finishing operations. Accuracy tests are carried out with the object of checking machine alignments and fundamental movements and determining the accuracy with which machines produce cylinders, threads, flat surfaces, etc. Most accuracy tests are made with conventional precision measuring equipment, but the complex errors revealed in some tests can only be analysed and recorded with special apparatus.

The economic significance of power and efficiency tests needs no emphasis. Recent research on machine tools has shown that power losses may amount to more than 50% of the total input power.

A machine's capacity to exploit modern cutting materials is most effectively assessed by practical machining tests. For many engineers there is an illusory simplicity about carrying out practical turning tests to compare the rates at which different lathes remove metal or produce finished surfaces. But if practical machining tests are to provide reliable comparisons of rates of metal removal, closer control than is possible in a production workshop must be maintained over such factors as tool grinding, material, cutting fluid, etc., and special equipment has been developed by the Association for this purpose.

Vibration in machine tools arises from unbalanced forces in rotating parts, faulty gearing, etc., and from the cutting action itself. No reliable information on means of eliminating vibration in machine tools has previously been available to engineering firms, and this subject is therefore occupying a prominent place in PERA's programmme.

Machine Tool Bearings

The requirements of rigidity and accuracy have led to the device of preloading rolling bearings, thereby eliminating end clearance. A limit is imposed on this, however, by a decrease in the life and increase in the operating temperature of a bearing as end clearance is reduced. Relatively large spindle displacements, sometimes of the order of 0·005 in. have been observed as a result of increases in bearing temperature during the warming-up period, and though this is not normally serious for general purpose centre lathes for example, it has obvious hazards when semi-automatic machines are engaged on repetition work.

Equipment is being designed and manufactured for an investigation into the accuracy and performance of rolling bearings for machine tools. Tests are being confined, in the first instance, to angular contact ball bearings, and will consist of bearing accuracy tests and practical tests on a finish turning lathe with the bearings mounted in a specially designed head.

Conclusions based on precise data secured from rigorous tests on machine tool accuracy and performance have often been augmented by recommendations arising directly from general observation. Recommendations of this type have related to the design of headstock and saddle controls, guards, protection of slides, finish of machine, etc.

The advent of cemented carbide cutting tools, rising costs of labour, and the demand for higher component quality are making it increasingly difficult for makers of production engineering equipment to provide, at a reasonable cost, machines of the necessary power, rigidity and versatility. A number of still largely unsolved problems are confronting makers and users but solutions will be found more readily as authoritative data becomes available as a result of research.

The Principles of Extraction and Refining of Metals

THE Institution of Metallurgists held a short refresher course on the above subject at Ashorne Hill on September 29th to October 1st inclusive. The first lecture, that dealing with physical chemistry and its use in extraction operations, was given by Dr. A. J. E. WELCH ; the second by Mr. E. J. PRYOR on the principles of mineral dressing in relation to initial extraction, followed by basic principles of ore reduction by Prof. C. W. DANNATT, and principles of refining by Dr. F. D. RICHARDSON, the concluding lecture being given by Dr. L. NORTHCOTT on fundamentals of the production of metal and alloy ingots.

Magnetic Clarifiers Prevent Clogging of Borehole

Two special Philips seven-disc magnetic Clarifiers have been installed at Messrs Richard Hill Limited of Middlesbrough, for removing scale from large quantities of water used during the hot "rolling" process in their rod mill. A borehole which had previously been used as a source of water supply, is now used for the disposal of approximately 650,000 gallons of water per week, and as the water carries scale in suspension in a finely powdered form, the problem was how to arrest this scale before entering and possibly silting up the borehole.

The standard clarifiers are manufactured with single or multiple magnetic discs, each of which handle up to 500 g.p.h. of coolant or lubricating fluid. They are in widespread use on grinding, honing, boring and many other machines.

Industrial Department, Philips Electrical Limited, Century House, Shaftesbury Avenue, London, W.C.2.

Staff Changes and Appointments

Mr. W. S. Steel, B.Sc.(Eng.), M.I.E.E., A.M.I.Mar.E., has been elected a Director of The British Thomson-Houston Co., Ltd. Born and educated in South Africa, Mr. Steel graduated at the Witwatersrand University in mechanical and electrical engineering and received the special award of the Vice-Chancellor's gold medal at the conclusion of his studies. Subsequently he joined the British Thomson-Houston Company as a student apprentice at Rugby and, on completing his course, he served in several departments and later held key appointments. In 1937, he went to South Africa as engineering representative of the Company. He returned to Britain in 1940 and held appointments in Government Ministries. In 1943 he returned to the Company to take over Admiralty work in the Marine Department and was appointed Manager of that Department in 1944 and of the Company's Home Sales in 1946.

Mr. R. M. Watts has been appointed Superintendent, Steel Products Department (Trafford Park and Stockton Works) of the Metropolitan-Vickers Electrical Co. Ltd. He succeeds Mr. T. Dooley who has transferred to the Hotpoint Electric Appliance Company, Ltd. Mr. Watts joined the Company as a Trade Apprentice in January, 1920, and after a period as Assistant Tool Engineer he became Tool and Planning Engineer in 1945. He was appointed General Development Engineer in 1948 and Assistant Superintendent at the beginning of the year.

Mr. S. B. Warder, Mechanical and Electrical Engineer, Southern Region, has been appointed Chief Officer (Electrical Engineering), Railway Executive Headquarters, in succession to Mr. C. M. Cock, who has been appointed General Manager of the Traction Department, English Electric Company Limited, and a director of the English Electric Export and Trading Company, Ltd.

Mr. W. Barr, Chief Metallurgist of Colvilles, Ltd., has succeeded Dr. C. Sykes as Chairman of the Divisional Panel of the Metallurgy Division of the British Iron and Steel Research Association.

Mr. H. A. Hoare has resigned his position with de Havilland Aircraft Co., Ltd., to join Aluminium Laboratories, Ltd., as a research metallurgist.

Mr. W. H. Henman has been re-elected President of the British Non-Ferrous Metals Federation for the year 1950–51.

Mr. J. S. Ramsden, M.I.E.E., has relinquished his seat on the Board of Directors of The British Thomson-Houston Co., Ltd., after more than forty years' service with the Company—fifteen of them as a Director. He is, however, remaining with the Company in a consultative capacity, and is retaining his seat on the Boards of The British Thomson-Houston Export Co., Ltd., Ferguson Pailin, Ltd., and the Switchgear Testing Co., Ltd. His friends and colleagues, therefore, will not entirely lose the stimulating benefits of his wide knowledge and human understanding, which they have so much appreciated in their frequent, and often almost daily, contacts with him.

While regretting Mr. Ramsden's decision to relinquish the arduous duties of Senior Commercial Director, his wide circle of friends will heartily congratulate him upon a long and effective service, not only for his Company but for the entire Electrical Engineering Industry, and wish him the fullest enjoyment of the well-earned quiet and leisure that even partial retirement should bring.

Mr. Maurice Solomon, F.C.G.I., M.I.E.E., has relinquished his seat on the Board of The General Electric Co., Ltd., on account of continued ill-health, a decision which will have been received with regret by his many friends, particularly of the older generation in the G.E.C. and the electrical industry. Mr. Solomon showed early promise of his subsequent brilliance. After a short period with Johnson Matthey & Co. and the Nernst Lamp Co., he joined The General Electric Co., Ltd., in 1903, to work in the experimental department of the Robertson Lamp Works. In 1904 he was transferred to Witton as Works Manager of the Carbon Works, and became General Manager of these Works at the end of the following year. He was appointed a Director of the G.E.C. in 1915 and in 1920 became Managing Director of Pirelli-General Cable Works, Ltd., a post which he held till 1928, when he relinquished it but remained on the Board. He took a very active interest in the affairs of the Cable Makers' Association.

Mr. B. Howard Williams has been appointed Foseco (Foundry Services, Ltd.) representative for the area of South Wales and South West England.

Mr. J. Moore-Ogilvie, late of Delapena and Son, Ltd., has been appointed Advertising and Publicity Manager to High Duty Alloys, Ltd., in succession to Mr. D. Courtney Embley.

Mr. R. Mather, of the Skinningrove Iron Co., Ltd., has been appointed Chairman of the Council of the British Iron and Steel Research Association in succession to Sir Andrew McCance, F.R.S., who has been elected President.

Lt.-Col. J. P. Hunt, Managing Director of The Hallamshire Steel and File Co., Ltd., has been appointed Chairman of the National Association of Rolled and Re-Rolled Steel Products.

Mr. F. R. Hutchings has resigned from W. H. Allen, Sons and Co., Ltd., to take up an appointment in the Research Department of the British Engine Boiler and Electrical Insurance Co., in Manchester.

Mr. F. H. Poole, Works Manager of Eva Brothers, Ltd., Manchester, has been appointed to the Board of Directors of the Company.

Mr. W. Sorby has resigned his position with Turton Brothers & Mathews, Ltd., to take up an appointment as Senior Metallurgist in charge of the Research Department of English Steel Corporation, Ltd., in Manchester.

Mr. G. L. Bailey, Director of the British Non-Ferrous Metals Research Association, has been elected Vice-Chairman of the Committee of Directors of Research Associations.

Mr. C. R. Tottle has resigned his post as Lecturer in Metallurgy, University of Durham, to take charge of the Metallurgical Laboratories at the Springfield Factory of the Atomic Energy Division of the Ministry of Supply.

Mr. H. J. Penn, who has been an Executive Director of Murex, Ltd., has been appointed Managing Director of the Company. Mr. H. C. Green and Lt.-Col. J. F. Todhunter, who are also Executive Directors, have been appointed General Managers, respectively, of the Rainham and Waltham Cross works.

The Iron and Steel Corporation of Great Britain announces that it has appointed Mr. S. S. Wilson to be its Secretary. Since 1948 Mr. Wilson has been an Under-Secretary in the Ministry of Supply. Prior to that he held the same rank in the Ministry of Transport.

Mr. G. M. Michie, M.A., A.Inst.P., recently joined the Research and Development Department of the British Steel Founders' Association in a senior executive capacity.

For a number of years Mr. Michie has been associated with steel castings metallurgy and is particularly well-known for his connection with the development and application of non-destructive testing.

Mr. D. G. Armstrong, A.R.S.M., B.Sc., A.M.I.M.M., has joined the staff of the Research Laboratories of The General Electric Company, Ltd., Wembley. He is in charge of the Mineral Dressing Group which works on behalf of their Fraser and Chalmers Engineering Works.

Mr. J. W. Cartlidge, of Dyson & Co. Enfield (1919) Ltd., has been elected Chairman of the Council of the Zinc Alloy Die Casters' Association. He will be assisted by Mr. E. B. Hill, of Charles Hill & Co., Ltd., and Mr. F. G. Woollard, of Birmingham Aluminium Castings (1903) Co., Ltd., as Deputy Chairmen.

Mr. J. G. Colvin has been awarded the B.Sc. degree (Metallurgy) of the University of Leeds and has joined the staff of Stewarts & Lloyds, Ltd., Corby.

Awards

Mr. R. Lindsay, who was recently appointed Technical Representative for Bradley & Foster, Ltd., in Yorkshire and the Northern Counties, has been awarded the Buchanan Silver Medal of the Institute of British Foundrymen.

Mr. E. F. Embley, who is a metallurgist with Magnesium Elektron, Ltd., has been awarded the Ph.D. degree of London University.

Mr. A. W. Armstrong has been awarded the Associateship of the Birmingham Central Technical College.

Mr. J. A. Evans has been awarded the B.Met. degree of the University of Sheffield.

Mr. G. H. Mitchell has been awarded the degree of B.Sc. in Applied Chemistry (Metallurgy) by Glasgow University.

Obituary

The announcement of the death, on September 16th, after a long illness, of Mr. George Senior, until recently a Director of General Refractories, Ltd., Sheffield, would be received with regret by his many friends. Mr. Senior, who was 60, had been associated with the Company for 31 years and was a Director for the last 15 years.

By the death, on October 3rd, of Sir John Jarvis, D.C.L., at his home in Godalming, Surrey, industry generally, particularly on Tyneside, loses one of its stalwarts. It will be remembered that during the early 1930's, when Britain was in the throes of a severe industrial depression, Sir John took a very active part in organising work facilities in one of the most hard hit areas and selected Jarrow as the hardest hit and most in need of real help. His name will long be revered as a result of efforts in that area. In addition to holding the Chairmanship of Sir W. G. Armstrong Whitworth & Co. (Ironfounders) Ltd., and its two associates, Armstrong Whitworth & Co. (Pneumatic Tools) Ltd. and Jarrow Metal Industries, Ltd., Sir John was also Chairman of Jarrow Tube Works, Ltd., J. & A. Churchill, Ltd., and J. Jarvis & Sons, Ltd. He was member of Parliament for Guildford for 15 years, but did not stand at the last general election.

Trade Publications

A further addition to the many excellent technical publications issued by The Mond Nickel Co., Ltd., has been received. It is based on the paper presented by Frank Hudson, F.I.M., to the congress of The American Foundrymen's Society in May of this year, and deals with all aspects of castings in aluminium alloys containing nickel, including early developments, recent metallurgical practice and modern production methods.

A tabulated summary of the many alloys available, combined with a wealth of illustrations showing foundry technique, etc., makes this publication valuable to engineers and designers in all industries. Copies may be obtained, free of charge, upon application to The Mond Nickel Co., Ltd., Sunderland House, Curzon Street, London, W.1.

Cellactite and British Uralite, Ltd., have issued a technical handbook of special value to those concerned with heat insulation. The handbook presents technical information and facts concerning Kimlo (Moler) insulating bricks, their composition, and their place in heat control and economy. Diatomite, of which these bricks are made, is one of nature's most interesting marine deposits, unique in occurrence and usefulness, and in this handbook its origin and characteristics are described and its insulating values discussed. Copies are available from Cellactite and British Uralite, Ltd., Terminal House, 52, Grosvenor Gardens, London, S.W.1.

Head Wrightson and Co., Ltd., Teesdale Iron Works Thornaby-on-Tees, have issued a new brochure on steel and alloy castings giving useful user information concerning these products. Copies may be obtained on application to the Company.

Zinc Alloy Die Casters' Association has issued a booklet dealing with zinc alloy die castings and productivity. The text matter is founded on an address given by Prof. T. U. Matthew, of Birmingham University, at a general meeting of the Association and draws attention to the great possibilities offered by the zinc alloy die casting process towards meeting the continued demand for increased productivity. A variety of components, selected as good examples of castings produced by this process, are illustrated. Those interested should apply for copies to the Association, Lincoln House, Turl Street, Oxford.

Wild-Barfield Electric Furnaces, Ltd., have issued a booklet giving much useful information on induction heating equipment. It deals with the furnace or machine by which radio frequency power is applied to the material or component to be heated. Types of machines are discussed and reference made to important features incorporated to safeguard personnel and equipment, and to applications. Descriptions of types are given and also examples of the work they perform. It is well produced and illustrated and copies may be obtained from Wild-Barfield Electric Furnaces, Ltd., Elecfurn Works, Watford By-pass, Watford, Herts.

British Timken, Ltd., has opened new offices at 93, Hope Street, Glasgow, C.2 and their representative in charge is Mr. H. F. Searle. The telephone number is Glasgow Central 7331–2.

CURRENT LITERATURE

Book Reviews

ENGINEERING METALLURGY

By Alexander P. Gwiazdowski, M.E., xv + 264 pages, 141 illustrations, 6¼ × 9½ in., published by C. C. Nelson Publishing Company, Appleton, Wisconsin, U.S.A.

MANY books have been written on the materials used by engineers, from the textbooks mainly for students to the many specialist books covering particular aspects concerned with the fabrication and treatment of metals and their alloys. The engineer and user, who is always seeking further knowledge about his materials, must pick his difficult way through a multitude of volumes in an endeavour to build up for himself a background of knowledge which will enable him to exercise greater discrimination in the selection of materials for different purposes. Many of these books have been written by those with a scientific rather than a practical background and this increases the difficulty of the engineer in finding the right guidance in meeting modern industrial requirements.

Normally the designer selects what he regards as the proper material for a component, but the increasing complexity of engineering makes heavy demands on the ability of the designer and, since metals and alloys play so large a part in engineering, the need for a proper appreciation of the materials available, their characteristics and treatment, was never so important as to-day when the selection for a particular purpose involves so many factors. Even the factors of cost and amenability to fabrication into specific shapes and the problems associated with the various products limit the choice, and often a material that gives good service, under a clearly defined set of conditions, fails if processing factors such as temperature, concentration, impurities and the like deviate far from the optimum values.

Selection of a material for any one component for a special purpose may necessitate a compromise because of opposing factors and a choice made that satisfies the more important conditions of service at the lowest cost. For such cases, and there are many, the importance of engineering metallurgy, which the author of this book emphasises as a help to the designing engineer, cannot be over-estimated, if he is to select materials and their treatments intelligently with a view to high quality products that are economical in service. Tests that are carried out as a check on materials to satisfy specification requirements are almost wholly concerned with engineering metallurgy and thus basic metallurgical information about the nature and characteristics of the commercially important metals and their alloys is of great importance not only to engineering designers but also to purchasing agents, production executives and to engineering students.

In preparing the present book on the subject the author had five objectives in view: concise and clear definitions, principles, selection of materials, selection of heat treatments, and engineering specifications, and, although they are dealt with in a very condensed form, these objectives are substantially met. The first two chapters deal with metals and their properties, then follow two chapters dealing with structures and compositions of ferrous alloys, and the properties, alloy compositions and uses of a number of metallic elements, metalloids, and the gases hydrogen, nitrogen and oxygen. The next nine chapters are concerned with ferrous materials: the various steelmaking processes, rolling, various steels and their uses, heat treatment, high-speed and tool steels, corrosion and heat resisting steels, processing rolled steels, cast irons and cast steels. There are two chapters to the light alloys, one to copper-base alloys and one to bearing metal, and the final chapter gives the various finished steel products of States in America. In addition to a useful index, several pages are given to review questions and to references for further reading.

The subject matter, it will be noted, is very comprehensive, and the author must have found a difficulty in keeping the text down to 264 pages, however, keeping in mind the purpose of the book, the lucid manner of presenting the information has definite advantages and, despite the fact that the book has been written primarily for American readers, it can be recommended as a means of overcoming a very real problem in engineering production.

W.A.

ELEKTROSTAHL–ERZEUGUNG

By Dr. Franz Sommer and Dr. Hans Pollock, xii + 338 pages, published by Stahleisen m.b.H., Dusseldorf, Germany, 1950. Price DM. 34.

THIS book is volume 8 of the series known as "Stahleisen Bücher," by the same publishers, all of which deal with particular technical subjects directly associated with iron and steel and written by experts. Since electric furnaces for steel melting were first introduced, in 1906, the annual world production of electric steel has reached a total exceeding ten million tons; this rapid development of electric steel is undoubtedly due to its superior properties and to advance in engineering science, which has involved the use of such steels. From the two-electrode furnace with a capacity of 1·5 tons to the present 100-ton rotary furnace and to the high-frequency furnace lies the difficult but successful development of metallurgy and electric technology, which the authors describe in an introductory chapter. The following five chapters are concerned with manufacture, properties and uses; their main subjects being: electro-technical fundamentals; refractory materials; construction of electric furnaces; working and metallurgical operation during melting and alloying; and the economics of electric steel production, etc.

The authors present a lucid, yet comprehensive, survey of electric steel production and of plant and equipment, which will be appreciated by steelmakers and particularly by scientific and practical metallurgists, electrical engineers, physicists, chemists as well as by constructional engineers and those concerned with the production of refractories, ferro-alloys, etc. The engineers of open-hearth steelmaking furnaces and of finishing plant, economists and steel merchants will also find much valuable information in this book. The achievements of the American electric steel industry are specially emphasised and the comprehensive summary of available knowledge should contribute substantially to

the rapid expansion of commercial interest in the use of electric steel.

A bibliography covers some 200 references to literature on the subject and a full name and author index will prove helpful. In addition, the text is amplified by numerous explanatory diagrams, 200 figures and many tables.

F.N.

RAW MATERIALS OF THE IRON AND STEEL INDUSTRY

By A. K. Osborne, A.Met., 31 pages, 5½ + 8½ in., paper covers, published by Purchasing Officers Association, Wardrobe Chambers, 146, Queen Victoria Street, London, E.C.4. Price 3s.

THIS booklet forms part of a Raw Material Survey Series of which some seventeen have so far been published by the Purchasing Officers Association. The present booklet is concerned with the raw materials of the iron and steel industry, although in view of the wide field involved detailed information has not been possible. The subject is approached strictly from an economic aspect and indications are given of sources, availability and consumption of various materials, together with a very brief outline of their uses and the methods by which they are produced. The principal materials are dealt with in alphabetical order and include chromium, cobalt, niobium, fluorspar, iron ores, limestone, manganese, molybdenum, nickel, silicon, tantalum, titanium, tungsten, and vanadium, while under the title of miscellaneous are included aluminium, boron, bismuth, calcium silicide, cerium, lead, magnesium, selenium, and tellurium. Coal and refractories have not been included; they are of major importance in industry as a whole and are considered in separate booklets in the series.

Although primarily designed to cover the Syllabus of the Association's final examination subject "Raw Materials (Economic and Geographic Survey)" this booklet has a much wider usefulness.

THE MACHINING AND MANIPULATION OF STAINLESS STEELS

By W. F. Walker, A.M.I.P.E., 78 pages, 17 illustrations 5 × 7 in., paper covers, published by Emmott & Co., Ltd., 31, King Street West, Manchester, 3. Price 3s. 6d.

THIS is one of the *Mechanical World's* Monographs (No. 57) and it deals with a subject about which useful information is, to a considerable extent, overdue. The lack of information on the machining and manipulation of stainless steels is doubtless due to the range of steels included, the effect of elements in their compositions in producing different structures and properties, particularly air-hardening properties which some of them possess. There are, of course, several chromium stainless steels which include 12% chromium, with a maximum of 0·12% carbon, 12–14% chromium with 0·3–0·4% carbon, and 16–18% chromium, with 0·65–0·7% carbon, all having a martensitic structure, none of which are particularly easy to machine or manipulate. The welding, machining and drawing properties of the 12% chromium alloy are fair, although the welding properties are improved by annealing and also when titanium or niobium is present to prevent air-hardening. The 12–14% and the 16–18% chromium alloys should be pre-heated and annealed for welding, and annealed for both machining and drawing. These represent only a few of the range of chromium alloys with a martensitic structure, there is also a range having a ferritic structure which vary much in their welding, machining and drawing characteristics. The range of chromium-nickel stainless steels is wider and here again the working characteristics vary considerably and much care is needed as well as experience to determine the best conditions for favourable results and this monograph will prove a great help to those engaged in the manipulation of these steels.

BRITISH IRON AND STEEL FEDERATIONS' STATISTICAL YEAR BOOK FOR 1948

PART II.—OVERSEAS COUNTRIES

Tabulated data of production and trade in iron and steel, xvi + 432 pages, with 13 maps. Published by the British Iron and Steel Federation, Steel House, Tothill Street, London, S.W.1. Price 15s.

THIS volume of statistics relating to the iron and steel industries of overseas countries is the third to be published by the British Iron and Steel Federation since the war. The difficulties encountered to present the statistical picture for 1946 were reduced for the 1947 volume, in the present volume, however, the picture for 1948 is more complete since information relating to Eire, Mexico and Southern Rhodesia is included for the first time, while additional statistics are provided for Austria, Brazil, Canada, Italy, Japan, Saar, Spain and Sweden. This volume can therefore be regarded as the most comprehensive statistical guide to the iron and steel industries of the world at present available. It contains detailed information relating to production and trade in iron and steel for nearly forty countries, including pre-war data wherever available. It also contains summary tables showing world production in iron ore, pig iron and steel, as well as a number of useful maps.

The abnormal delay which still occurs in many countries before official statistics are issued is largely responsible for the late publication of this volume; in part, however, it is a reflection of difficulties in the printing trade in the London area. The issue preserves continuity with previous volumes but is more complete and therefore more useful.

NON-FERROUS METALS HANDBOOK

CHARLES CLIFFORD & SON, LTD., have recently published the tenth edition of their trade handbook, which was first published in 1887. This latest edition has been completely revised and redesigned to meet present day requirements and is enlarged by the inclusion of a number of new tables of weights, particularly relative to phosphor bronze, a major product of this Company. However, the basic character of this handbook remains the same as the first edition and provides a source of ready reference to matters connected with non-ferrous metals. Those familiar with earlier editions will know how useful the handbook is and need only to be advised that a new edition is available, but those users of non-ferrous metals who are unfamiliar with it, are advised to obtain a copy from Charles Clifford & Son, Ltd., Dogpool Mills, Birmingham, 30.

The Creep of a Nominally Isotropic Magnesium Alloy at Normal and Elevated Temperatures Under Complex Stress Systems

By A. E. Johnson, M.Sc., M.Sc.Tech., A.M.I.Mech.E.

(Communication from the National Physical Laboratory)

The work described in this paper is part of a programme of creep, plastic strain and relaxation tests at high temperatures, and under general stress systems being carried out in the Engineering Division, National Physical Laboratory. The purpose of the present investigation was to examine the nature of the creep properties of an initially isotropic cast magnesium alloy at temperatures of 20° and 50° C., and under general stress systems. Some forty to fifty tests consisting of pure tensile, pure torsion, and complex stress creep tests (the latter under various combinations of simple tensile and torsion stresses) have been performed on the magnesium alloy at 20° and 50° C. The results of these tests have been analysed and equations for the stress-strain relations over the temperature range concerned have been derived.

Introduction

IN two previous papers (15 and 16) the present author has made a fairly comprehensive statement of the theoretical and experimental work which has been done in attempts to establish the relations between creep rates and the complex stress systems producing them. It is not intended in this paper to repeat this statement, but a description will nevertheless be given of the general results and conclusions obtained in the two above-mentioned papers, dealing with investigations similar to those described in the present paper, but using as working materials a 0·17% C. steel, and an aluminium alloy (RR59), respectively.

The work on the 0·17% C. steel was performed on behalf of the B.E.A.I.R.A. J/E Committee, in which some eighty creep tests under pure tension, pure torsion, and various combinations of simple tension and torsion stresses were made at 350, 450 and 550° C.[15]. The results of the tests at 350° C. indicated that, at this temperature, the material was essentially isotropic except at the highest stresses, and here it seemed probable that the anisotropy may have arisen as a result of directional properties acquired under a considerable plastic strain on loading. The octahedral shear strain appeared for all stress systems to be closely a function of the octahedral shear stress, i.e., the Hencky criterion of plastic strain appeared to be fulfilled approximately for the material.

The principal creep rate-stress relations at a specific period over the whole range of stress and time investigated could reasonably be represented by equations of the form :—

$$C_1 = \left\{ A\left[\Sigma(\sigma_1-\sigma_2)^2\right] + A^1\left[\Sigma(\sigma_1-\sigma_2)^2\right]^m \right\}\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right] \text{ etc.}$$

where C_1, etc. are principal creep rates under the principal stress system σ_1, O, $-\sigma_2$, A and A^1 and m are constants, and $m = 2{\cdot}5$. The effect of the anisotropy present at the highest stresses appeared to be merely to redistribute the creep strain between secondary and minor principal stress directions, leaving the major principal creep rate as it would have been for complete isotropy.

For the moderate and lower ranges of stresses the relation becomes

$$C_1 = A\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right] \quad \text{etc.}$$

These equations conform with the St. Venant-von Mises general type, and also since

$$\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right] \equiv \left[(\sigma_1-\sigma_2)^3-(\sigma_3-\sigma_1)^3\right]$$

they conform with the Bailey type of equation for $n = 3$.

At 450° C. slight anisotropy was shown at moderate and low stresses, although the further effect noted at 350° C. again occurs at the highest stresses with probably the same origin. At 550° C., however, a very complex condition of anisotropy occurred. It appeared possible that the anisotropy exhibited at 450° and 550° C. was associated with metallurgical changes, occurring in the structure of the material at high temperatures. However, at 450° and 550° C. despite the anisotropy present, it appeared probable that the Hencky theory was still the basis of the behaviour of the material.

At 450° C. equations of the form

$$C_1 = \left\{ A\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{m_1} + A^1\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{m_2} \right\}\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right] \quad \text{etc.}$$

where A_1 and A^1, m_1 and m_2 and C are constants, C referring to the anisotropy present. $m_1 = 0{\cdot}45$, $m_2 = 2{\cdot}45$ or alternately

$$C_1 = \left\{ A + A^1\left[\Sigma(\sigma_1-\sigma_2)^2\right]^m \right\}\left[(\sigma_1-\sigma_2)^n - D(\sigma_2-\sigma_3)^n\right] \text{etc.}$$

where $m = 2$, $n = 1{\cdot}9$ and D is a constant referring to the anisotropy present, appeared to represent the data well.

At moderate and lower ranges of stress the above equations become

$$C_1 = \left\{ A\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{m_1} \right\}\left[(\sigma_1-\sigma_2) - C(\sigma_3-\sigma_1)\right] \quad \text{etc.}$$

$$\text{or} \quad C_1 = A\left[(\sigma_1-\sigma_2)^n - D(\sigma_2-\sigma_3)^n\right] \quad \text{etc.}$$

At 550° C. it was not possible to formulate general equations representing the stress/creep-rate relations. There was some evidence, however, that the bases of such equations would be similar to the general form given above for 350° C. and 450° C.

The work on the RR59 alloy was performed on behalf of the Properties and Mechanics of Materials Committee of the Mechanical Engineering Research Board; some forty to fifty tests consisting of pure tensile, pure torsion, and complex stress creep tests (under various combinations of simple tensile and torsion stresses) were made on the aluminium alloy at 150° and 200° C.

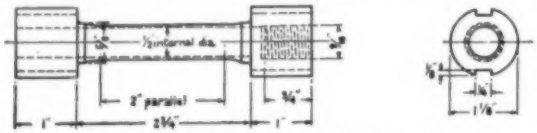


Fig. 1.—Form of test-piece used in all tests.

The results of these tests indicated that at 150° and 200° C. the material behaved isotropically over a range of moderate and lower stresses. At 200° C. combined stress tests in higher regions of stress showed some anisotropy, which may possibly have arisen as the result of the considerable initial plastic strain at such higher stresses. Combined stress tests were not made at high stresses at 150° C., but had this been done it is possible that anisotropy similar to that at 200° C. would have been shown. Over the whole stress range investigated, the material appeared to obey the Hencky, or shear-strain-energy, criterion of plastic strain.

At moderate and low stresses the creep-rate stress relations were well represented at 150° C. by equations of the type

$$C_1 = A\left[(\sigma_1-\sigma_2)-(\sigma_2-\sigma_1)\right] \quad \text{etc.}$$

and at 200° C. by

$$C_1 = A\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{0\cdot5}\left[(\sigma_1-\sigma_2)-(\sigma_2-\sigma_1)\right] \quad \text{etc.}$$

Over the whole range of stress the creep rate stress relations appeared to be based at 150° C. on general equations of the type

$$C_1 = \left[A + D_1\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{m_1} + D_2\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{m_2}\right]\left[(\sigma_1-\sigma_2)-(\sigma_2-\sigma_1)\right]$$

and at 200° C. on general equations of the type

$$C_1 = \left[A\left\{(\sigma_1-\sigma_2)^2\right\}^{m_1} + B\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{m_2}\right]\left[(\sigma_1-\sigma_2)-(\sigma_2-\sigma_1)\right]$$

At moderate and low stresses the above equations simplify into the equations previously given. The anisotropy occurring at high stresses, in the combined stress tests, was such in all cases as to tend to equalise the values of major and minor creep rates, and to render wall thickness creep approximately zero, (this of course is the state of affairs in a pure torsion test). These conditions can be represented by equations of the general type,

$$C_1 = F\left[\Sigma(\sigma_1-\sigma_2)^2\right]\left[(\sigma_1-\sigma_2)-(\sigma_2-\sigma_1)\right]$$

$$C_2 = F\left[\Sigma(\sigma_1-\sigma_2)^2\right]\left[B_1(\sigma_2-\sigma_3)-(\sigma_1-\sigma_2)\right]$$

$$C_3 = F\left[\Sigma(\sigma_1-\sigma_2)^2\right]\left[(\sigma_3-\sigma_1)-B_1(\sigma_3-\sigma_2)\right]$$

where B_1 is dependent upon the applied stress system, and exceeds unity in all cases except pure torsion. The above equations correspond with the state of isotropy for pure tension, which is in accordance with the experimental facts. This was also the type of anisotropy existing in the 0·17% C. steel at high stresses.

Particulars of the Magnesium Alloy Tested at 20 and 50° C.

The material was supplied by Messrs. F. A. Hughes and Co. Ltd., of Clifton Junction, Manchester, in the form of three continuous-cast billets, 12 in. diameter and 12 in. long. Microscopic examination of the material indicated a satisfactorily small grain size after heat treatment at 420° ± 5° C. for 4 hours, the temperature then being raised to 525° C., and maintained at this temperature ± 5° C. for 4 hours, before cooling to room temperature in about 10 hours.

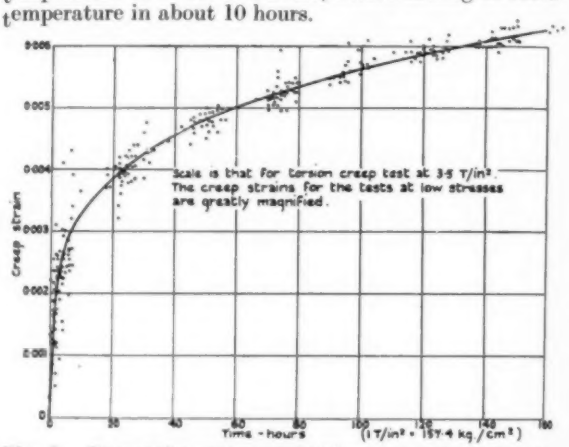


Fig. 2.—Composite creep-strain/time curve for all tests at 20° C.

Creep tests at 1¼ tons/sq.in. and 150° C., on material cut longitudinally, circumferentially and radially from each of the billets, gave closely similar results, and the creep properties were independent of the position of the specimen in the block. The indication was that the block was in a satisfactory condition of isotropy from the point of view of the creep tests to be carried out.

A separate billet was used for each temperature, and all test-pieces used in the tests to be described were cut longitudinally from the block.

The approximate composition of the magnesium alloy was 98% Mg., 2% Al.

Form of Specimen Used

The tubular testpiece used was of the form shown in Fig. 1. It was 0·5 in. external diameter, and had a wall thickness of 0·030 in. ± 0·0005 in. over a 2 in. parallel portion. The method of preparation was that stated in the earlier papers[15,16], for the testpieces concerned in the work described therein.

A measure of the degree of oxidation to be expected at 50° C. was obtained by suspending pieces of the magnesium alloy in furnaces maintained at that temperature for 200 hours. It was found that the oxidation was negligible. The stresses in the tests therefore remained equal to their initial value throughout the test period.

Description of Test Apparatus

The main features of the testing machine, and strain measuring device used in the tests have been described earlier[15,16].

Experimental Work

Only one creep test was carried out on each specimen. The tests lasted about 150 hours, readings of creep strain being made at frequent intervals during the first day and thereafter at intervals of a day. For the majority of tests, the stresses were chosen to give a range of creep rates, in the direction of maximum principal stress, varying between 10^{-5} and 10^{-7} per hour, but one or two tests made to determine the trend of the characteristic creep-rate/stress curves at high stresses gave rates exceeding the upper value.

The creep rates in the three directions of principal stress were computed from the measured axial and shear creep rates by means of the formulae

$$C_1 = C_a + \frac{C_c}{2}\left[\sqrt{(t/2s)^2+1} - t/2s\right]$$

$$C_2 = C_a - \frac{C_c}{2}\left[t/2s + \sqrt{(t/2s)^2+1}\right]$$

$$C_3 = C_c\, t/2s - 2C_a$$

The derivation of these formulae is given in the Appendix of Ref. 2 of the Bibliography.

The octahedral shear creep rate was computed from the formula

$$C_o = {}^2/_3\left[\Sigma\,(C_1 - C_2)^2\right]^{\frac{1}{2}}$$

This corresponds to the octahedral shear stress

$$\sigma_o = {}^1/_3\left[\Sigma\,(\sigma_1-\sigma_2)^2\right]^{\frac{1}{2}}$$

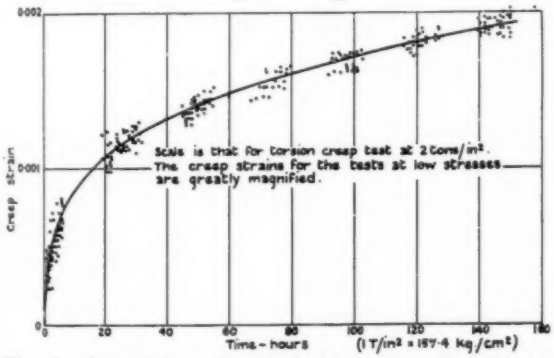


Fig. 3.—Composite creep-strain/time curve for all tests at 50° C.

On account of the rather high accuracy to be obtained in the pure torsion tests, enough of these tests were performed to enable the main features of the creep rate stress characteristic curve under pure torsion to be well mapped out, thus forming a guide to the likely form of similar relations for other stress systems under which fewer tests were made.

At 20° C. six pure torsion tests, four pure tension tests, and two or three tests in each of the stress systems, $t/s = 0{\cdot}4$, $0{\cdot}8$, $1{\cdot}5$ and $3{\cdot}0$ were made; while at 50° C. seven pure torsion, five pure tension and two or three tests in the stress systems $t/s = 0{\cdot}4$, $0{\cdot}8$, $1{\cdot}5$ and $3{\cdot}0$, and one in the stress system $t/s = 6$ were made.

Results of Experimental Work

Curves of the axial and shear creep strains plotted* against time, over a testing period of 150 hours for each test, were found in all cases to have the same geometrical form for each individual temperature. To determine the common form as precisely as possible, a comparison of the curves was made by plotting all the results in one diagram as in Figs. 2 and 3 which show the composite curves for all strain-time curves at 20 and 50° C.

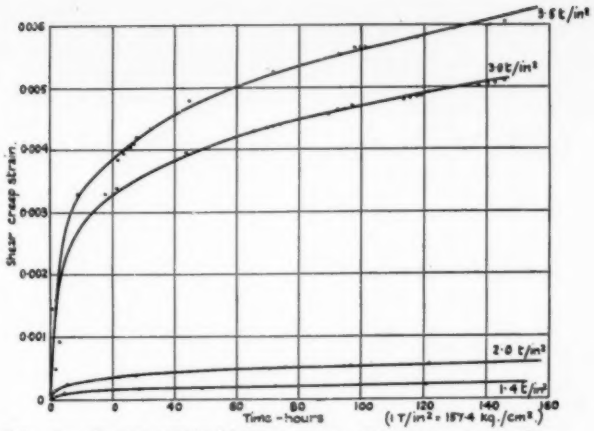


Fig. 4.—Creep-strain/time curves under pure torsion stresses at 20° C.

Since the creep readings in the torsion tests were less affected by temperature variations than those in other tests, the mean form of the curves for the pure torsion tests was first ascertained and plotted to a scale equivalent to that of a test at one of the highest torsion stresses. The creep readings for each of the other tests were plotted to modified scales, of suitable magnitude, to make the enhanced readings of each individual test fit the mean curve as closely as possible. The mean curve form for all the tests was then drawn through the points as shown in Figs. 2 and 3.

All the curves for the individual tests were drawn by appropriate reduction of scale, and were therefore geometrically similar. Errors in tests giving smaller strains are considerably magnified in Figs. 2 and 3.

A selection of the curves for individual tests are shown in Figs. 4 to 7 for the two temperatures concerned.

The composite curve form is such that the creep rate varies with time as follows :—

Temperature °C. of Test		Period of Test Hours					
		150	100	50	25	10	5
20	Ratio of Creep Rate to that at 150 hrs.	1	1·08	1·83	3·4	6·6	13·2
50	ditto	1	1·3	1·95	3·65	7·5	11·3

Tables I and II, respectively, give the experimental values for the axial and shear creep rates in the various tests at 150 hours for the two temperatures 20° and 50° C. The values of the principal and octahedral creep rates given in Tables I and II have been computed for test periods of 150 hours at 20° and 50° C., making use of the equations given under the respective tables. The principal creep rates and octahedral plane creep rates at other periods may be computed from the ratios above.

It will be noted from Tables I and II that at neither temperature is any axial creep shown in the pure torsion

* The creep strain shown is exclusive of the initial plastic strain in all cases. Previous work has shown, however, that the characteristics of this portion of the strain, though differing in kind from the subsequent creep strain, nevertheless exhibit geometrical similarity among individual curves of various stress systems. The characteristics of this initial plastic strain are to be dealt with in detail in a subsequent paper.
It will be realised that the geometrical similarity of curve form exists only for a limited range of stress and time, but this range will cover the great majority of the likely field of practical use of the material.

TABLE I.—RESULTS OF COMBINED STRESS CREEP TESTS ON MAGNESIUM ALLOY AT 20° C. COMPARED WITH VALUES BASED UPON THEORETICAL

Applied Tensile Stress t T/sq. in.	Applied Shear Stress s T/sq. in.	Principal Stresses ($\sigma_3 = o$) σ_1 T/sq. in.	σ_2 T/sq. in.	Octahedral Shear Stress σ_c T/sq. in.	Axial Creep Rate C_a in./in./hr. $\times 10^{-6}$	Shear Creep Rate C_c in./in./hr. $\times 10^{-6}$	Experimental values of Principal Creep Rates in./in./hr. $\times 10^{-6}$ C_1	C_2	C_3	Octahedral Plane Creep Rate in./in./hr. $\times 10^{-6}$	Ratio $t/3s$	Ratio C_a/C_c	Theoretical Principal Creep Rates according to equations shown below* C_1	C_2	C_3
													in./in./hr. $\times 10^{-6}$		
6	0	6	0	2·82	7·8	—	7·8	−3·9	−3·9	11·0	—	—	10·4	−5·2	−5·2
5	0	5	0	2·36	4·2	—	4·2	−2·1	−2·1	$5{\cdot}9_8$	—	—	3·5	$-1{\cdot}7_5$	$-1{\cdot}7_5$
4	0	4	0	1·89	1·5	—	1·5	$-0{\cdot}6_5$	−0·6	1·85	—	—	1·15	−0·58	−0·58
3	0	3	0	1·41	$0{\cdot}32_5$	—	$0{\cdot}32_5$	$-0{\cdot}16_5$	$-0{\cdot}16_5$	0·46	—	—	0·42	−0·21	−0·21
0	3·5	3·5	−3·5	2·85	—	12·5	6·4	−6·4	0	10·3	—	—	9·65	−9·65	0
0	3·0	3·0	−3·0	2·42	—	9·7	$4{\cdot}8_5$	−4·8	0	7·9	—	—	3·54	−3·54	0
0	2	2	−2·0	1·63	—	1·1	0·55	−0·55	0	0·9	—	—	$0{\cdot}57_5$	$-0{\cdot}57_5$	0
0	1·4	1·4	−1·4	1·14	—	0·5	0·25	−0·25	0	0·41	—	—	0·21	−0·21	0
0	1·0	1·0	−1·0	0·82	—	0·27	$0{\cdot}13_5$	$-0{\cdot}13_5$	0	0·22	—	—	0·10	−0·10	0
0	0·7	0·7	−0·7	0·57	—	0·12	0·06	−0·06	0	0·10	—	—	0·05	−0·05	0
1·0	2·5	$3{\cdot}0_5$	$-2{\cdot}0_5$	2·09	0·28	2·5	1·31	−1·25	−0·06	2·09	—	—	1·73	−1·52	−0·21
0·4	1·0	$1{\cdot}22_5$	−0·82	0·84	$0{\cdot}017_5$	0·17	$0{\cdot}092_5$	$-0{\cdot}081_5$	−0·011	0·14	0·133	0·132	0·116	−0·10	$-0{\cdot}01_5$
0·6	1·5	1·84	−1·23	1·26	0·051	0·4	$0{\cdot}21_5$	$-0{\cdot}19_2$	−0·022	$0{\cdot}33_2$	0·135	0·128	$0{\cdot}28_5$	−0·25	$-0{\cdot}03_5$
2·0	2·5	3·69	−1·69	2·24	1·1	4·85	2·76	−2·5	−0·26	4·3	—	—	2·55	−1·98	−0·57
1·0	1·25	1·85	−0·85	1·12	0·067	0·25	$0{\cdot}15_5$	$-0{\cdot}12_5$	−0·031	0·25	0·267	0·268	0·23	−0·18	−0·05
0·6	0·75	1·11	−0·51	0·67	0·029	0·11	$0{\cdot}015_5$	−0·052	−0·014	0·099	0·267	0·264	0·077	−0·06	−0·017
3·0	2·0	3·99	−0·99	2·16	1·4	4·0	2·4	−2·6	+0·2	3·98	—	—	2·14	−1·42	−0·72
1·8	1·2	2·4	−0·6	1·3	0·13	0·31	0·21	−0·19	−0·02	0·39	0·5	0·42	0·33	−0·22	−0·11
1·0	0·67	1·33	−0·33	0·72	0·064	0·13	0·097	−0·066	−0·031	0·14	0·5	0·49	0·091	−0·061	−0·031
5	1·67	5·5	−0·5	2·71	5·5	9·4	7·7	−8·9	+1·2	14·5	—	—	8·05	−4·55	−3·5
1·8	0·6	2·0	−0·18	0·98	$0{\cdot}16_5$	$0{\cdot}16_5$	0·19	−0·11	−0·081	0·27	1·0	1·0	0·18	−0·10	−0·08
1·5	0·5	$1{\cdot}6_5$	−0·15	$0{\cdot}81_5$	0·06	0·06	0·069	−0·04	−0·029	0·01	1·0	1·0	0·12	−0·067	−0·052

* $C_1 = \left[A \left\{ \Sigma (\sigma_1-\sigma_2)^2 \right\}^{0.5} + B \left\{ \Sigma (\sigma_1-\sigma_2)^2 \right\}^2 \right] \left[(\sigma_1-\sigma_2) - (\sigma_2-\sigma_1) \right]$ etc. where $A = 1{\cdot}39 \times 10^{-3}$ $B = 2 \times 10^{-11}$

TABLE II.—RESULTS OF COMBINED STRESS CREEP TESTS ON MAGNESIUM ALLOY AT 50° C. COMPARED WITH VALUES BASED UPON THEORETICAL

Applied Tensile Stress t T/sq. in.	Applied Shear Stress s T/sq. in.	Principal Stresses ($\sigma_3 = o$) σ_1 T/sq. in.	σ_2 T/sq. in.	Octahedral Shear Stress σ_c T/sq. in.	Axial Creep Rate C_a in./in./hr. $\times 10^{-6}$	Shear Creep Rate C_c in./in./hr. $\times 10^{-6}$	Experimental Values of Principal Creep Rates in./in./hr. $\times 10^{-6}$ C_1	C_2	C_3	Octahedral Plane Creep Rate in./in./hr. $\times 10^{-6}$	Ratio $t/3s$	Ratio C_a/C_c	Theoretical Principal Creep Rates according to equations shown below* C_1	C_2	C_3
													in./in./hr. $\times 10^{-6}$		
4	0	4	0	1·89	7·1	—	7·1	$-3{\cdot}6_5$	$-3{\cdot}6_5$	1·0	—	—	5·33	−2·67	−2·67
3	0	3	0	1·41	1·34	—	1·34	−0·67	−0·67	1·9	—	—	1·04	−0·52	−0·52
2·5	0	2·5	0	1·18	0·76	—	0·76	−0·38	−0·38	1·07	—	—	0·7	−0·35	−0·35
1·91	0	1·91	0	0·9	0·44	—	0·44	−0·22	−0·22	0·62	—	—	0·46	−0·23	−0·23
1·5	0	1·5	0	0·71	0·42	—	0·3	−0·15	−0·15	0·42	—	—	0·32	−0·16	−0·16
0	2·5	2·5	−2·5	2·04	—	12·8	6·1	−6·4	0	10·5	—	—	9·6	−9·6	0
0	2	2	−2	1·64	—	4·6	2·3	−2·3	0	$3{\cdot}7_5$	—	—	$1{\cdot}6_5$	$-1{\cdot}6_5$	0
0	1·55	1·55	−1·55	1·27	—	1·3	0·65	−0·65	0	1·06	—	—	0·69	−0·69	0
0	1·0	1·0	−1·0	0·82	—	0·58	0·29	−0·29	0	0·47	—	—	$0{\cdot}34_5$	$-0{\cdot}34_5$	0
0	0·5	0·5	−0·5	0·41	—	0·29	$0{\cdot}14_5$	$-0{\cdot}14_5$	0	0·23	—	—	0·13	−0·13	0
0	$0{\cdot}32_5$	$0{\cdot}32_5$	$-0{\cdot}32_5$	0·26	—	0·116	0·058	−0·058	0	0·095	—	—	0·07	−0·07	0
0	0·25	0·25	−0·25	$0{\cdot}20_4$	—	0·078	0·039	−0·039	0	0·064	—	—	0·05	−0·05	0
0·8	2	2·44	−1·64	$1{\cdot}67_5$	0·49	3·1	1·76	−1·4	−0·36	2·63	—	—	2·03	−1·78	−0·25
0·5	1·25	1·53	−1·03	$1{\cdot}04_5$	0·13	0·94	$0{\cdot}51_5$	$-0{\cdot}44_5$	−0·07	0·79	0·134	0·138	0·52	−0·46	−0·06
0·3	0·75	0·92	−0·62	0·63	0·06	0·45	$0{\cdot}24_5$	$-0{\cdot}21_5$	−0·03	0·38	0·134	0·134	0·26	$-0{\cdot}22_5$	$-0{\cdot}03_5$
1·6	2·0	2·96	−1·36	1·8	2·0	5·6	3·89	−2·13	−1·76	4·95	—	—	3·48	−2·71	−0·77
0·8	1·0	1·48	−0·68	0·9	0·2	0·67	0·43	−0·30	−0·13	0·62	0·266	0·297	$0{\cdot}43_5$	−0·34	$-0{\cdot}09_5$
0·4	0·5	0·74	−0·34	$0{\cdot}4_5$	0·05	0·23	0·14	−0·11	−0·03	0·21	0·266	0·261	0·16	$-0{\cdot}12_5$	$-0{\cdot}03_5$
2·1	1·4	2·8	−0·7	1·51	1·15	2·3	1·72	−1·15	−0·57	2·48	0·5	0·5	1·3	−0·87	−0·43
1·5	1·0	2·0	−0·5	1·08	0·40	0·75	0·59	−0·35	−0·24	0·84	0·5	0·53	$0{\cdot}58_5$	−0·39	$-0{\cdot}19_5$
0·75	0·5	1·0	−0·25	0·54	0·15	0·3	$0{\cdot}22_5$	−0·15	$-0{\cdot}07_5$	$0{\cdot}32_5$	0·5	0·5	$0{\cdot}21_5$	$-0{\cdot}14_5$	−0·07
$3{\cdot}7_5$	$1{\cdot}2_5$	4·13	−0·38	2·05	5·6	4·8	6·35	−2·35	−4	9·1	—	—	11·2	−6·35	−4·85
2·0	0·67	$2{\cdot}20_5$	$-0{\cdot}20_5$	1·09	0·53	0·52	0·61	−0·33	−0·28	$0{\cdot}86_5$	1·0	1·02	0·61	$-0{\cdot}34_5$	−0·26
1·0	0·33	1·10	−0·10	$0{\cdot}54_5$	0·19	0·18	0·22	−0·11	−0·11	0·31	1·01	1·05	0·22	$-0{\cdot}12_5$	$-0{\cdot}09_5$
1·0	0·67	1·11	−0·11	$1{\cdot}95_5$	6·8	2·25	6·99	−0·18	−6·81	11·3	—	—	7·6	−3·98	−3·67

* $C_1 = \left[A \left\{ \Sigma (\sigma_1-\sigma_2)^2 \right\}^{0.215} + B \left\{ \Sigma (\sigma_1-\sigma_2)^2 \right\}^{.5} \right] \left[(\sigma_1-\sigma_2) - (\sigma_2-\sigma_1) \right]$ etc.,
where $A = 7{\cdot}8 \times 10^{-3}$, $B = 1{\cdot}5 \times 10^{-11}$

† $C_1 = \left[A + B \left\{ \Sigma (\sigma_1-\sigma_2)^2 \right\}^{0.72} \right] \left[(\sigma_1-\sigma_2)^{1.42} - (\sigma_2-\sigma_1)^{1.42} \right]$ etc.,
where $A = 8{\cdot}9 \times 10^{-3}$, $B = 1{\cdot}41 \times 10^{-11}$

tests*. Again in all cases except those of one or two tests at 20° C. the wall thickness creep is negative; in the two exceptional cases it becomes positive. It will be shown later that in these two cases anisotropy occurs, probably arising from the degree of plastic strain incurred on loading.

Consideration of the Degree of Isotropy of the Material at 20° and 50° C.

As indicated in a foregoing paragraph, creep tests at 150° C. and 1½ tons/sq.in. on solid specimens taken from the original billet in three directions at right angles indicated that the creep characteristics of the material were closely similar in the three directions and reasonably isotropic behaviour in subsequent tests on tubular specimens was therefore to be expected, always provided that the imposed degree of strain or the actual working temperature, were not in themselves sufficient to give rise to anisotropy.

Preparatory to performing the main body of the tests, a further test was made in tension upon a tubular specimen at 1¼ tons/sq.in. and 150° C. The change in diameter and wall thickness of the specimen during the test period were measured and compared with the axial strain. The diametral strain was 0·65% and the wall thickness strain was of the same order; the axial strain was 1·2%. Evidently the secondary strains were roughly half the longitudinal strain and the material was thus indicated to be reasonably isotropic. This test,

* Compare Ref. 15 and 16, and 2.

CONSIDERATIONS. ALL CREEP RATES ARE MEASURED AT 150 HOURS

Theoretical Principal Creep Rates according to equations shown below†		
C_1	C_2	C_3
in./in./hr. × 10^{-6}		
$10{\cdot}1_5$	$-5{\cdot}07$	$-5{\cdot}07$
$3{\cdot}4$	$-1{\cdot}7$	$-1{\cdot}7$
$1{\cdot}14$	$-0{\cdot}57$	$-0{\cdot}57$
$0{\cdot}43$	$-0{\cdot}21_8$	$-0{\cdot}21_8$
$8{\cdot}95$	$-8{\cdot}95$	0
$3{\cdot}32$	$-3{\cdot}32$	0
$0{\cdot}55$	$-0{\cdot}55$	0
$0{\cdot}21$	$-0{\cdot}21$	0
$0{\cdot}10$	$-0{\cdot}10$	0
$0{\cdot}049$	$-0{\cdot}049$	0
$1{\cdot}66$	$-1{\cdot}42$	$-0{\cdot}24$
$0{\cdot}115$	$-0{\cdot}098$	$-0{\cdot}017$
$0{\cdot}285$	$-0{\cdot}24$	$-0{\cdot}04_5$
$2{\cdot}47$	$-1{\cdot}85$	$-0{\cdot}62$
$0{\cdot}21_5$	$-0{\cdot}161$	$-0{\cdot}054$
$0{\cdot}054$	$-0{\cdot}033$	$-0{\cdot}021$
$2{\cdot}1$	$-1{\cdot}33$	$-0{\cdot}77$
$0{\cdot}30$	$-0{\cdot}19$	$-0{\cdot}11$
$0{\cdot}09$	$-0{\cdot}057$	$-0{\cdot}033$
$7{\cdot}82$	$-4{\cdot}28$	$-3{\cdot}54$
$0{\cdot}18$	$-0{\cdot}10$	$-0{\cdot}08$
$0{\cdot}12$	$-0{\cdot}066$	$-0{\cdot}054$

† $C_i = \left[A + B \left\{ \Sigma (\sigma_1 - \sigma_2)^2 \right\}^{2.5} \right] \left[(\sigma_i - \sigma_k)^3 - (-1)\ (\sigma_k - \sigma_i)^3 \right]$

where $A = 2 \times 10^{-3}$ $B = 2{\cdot}7 \times 10^{-12}$

(Bailey adopts the convention that, when $(\sigma_i - \sigma_j)$ is negative $(\sigma_i - \sigma_j)^n$ is to be evaluated as $-(\sigma_j - \sigma_i)^n$ (i, j = 1, 2, 3).

CONSIDERATIONS. ALL CREEP RATES ARE MEASURED AT 150 HOURS

Theoretical Principal Creep Rates according to equations shown below†			Theoretical Principal Creep Rates according to equations shown below‡		
C_1	C_2	C_3	C_1	C_2	C_3
in./in./hr. × 10^{-6}			in./in./hr. × 10^{-6}		
$4{\cdot}7$	$-2{\cdot}3_5$	$-2{\cdot}3_5$	$5{\cdot}33$	$-2{\cdot}67$	$-2{\cdot}67$
$1{\cdot}0$	$-0{\cdot}5$	$-0{\cdot}5$	$1{\cdot}04$	$-0{\cdot}52$	$-0{\cdot}52$
$0{\cdot}69$	$-0{\cdot}34_5$	$-0{\cdot}34_5$	$0{\cdot}7$	$-0{\cdot}35$	$-0{\cdot}35$
$0{\cdot}45$	$-0{\cdot}22_5$	$-0{\cdot}22_5$	$0{\cdot}46$	$-0{\cdot}23$	$-0{\cdot}23$
$0{\cdot}32$	$-0{\cdot}16$	$-0{\cdot}16$	$0{\cdot}32$	$-0{\cdot}16$	$-0{\cdot}16$
$7{\cdot}78$	$-7{\cdot}78$	0	$9{\cdot}6$	$-9{\cdot}6$	0
$1{\cdot}47$	$-1{\cdot}47$	0	$1{\cdot}6_5$	$-1{\cdot}6_5$	0
$0{\cdot}65$	$-0{\cdot}65$	0	$0{\cdot}69$	$-0{\cdot}69$	0
$0{\cdot}33$	$-0{\cdot}33$	0	$0{\cdot}34_5$	$-0{\cdot}34_5$	0
$0{\cdot}12$	$-0{\cdot}12$	0	$0{\cdot}13$	$-0{\cdot}13$	0
$0{\cdot}06_5$	$-0{\cdot}06_5$	0	$0{\cdot}07$	$-0{\cdot}07$	0
$0{\cdot}04_5$	$-0{\cdot}04_5$	0	$0{\cdot}05$	$-0{\cdot}05$	0
$1{\cdot}8$	$-1{\cdot}55$	$-0{\cdot}25$	$2{\cdot}03$	$-1{\cdot}83$	$-0{\cdot}20$
$0{\cdot}53$	$-0{\cdot}46$	$-0{\cdot}07$	$0{\cdot}52$	$-0{\cdot}47_5$	$-0{\cdot}04_5$
$0{\cdot}24_5$	$-0{\cdot}21$	$-0{\cdot}03_5$	$0{\cdot}26$	$-0{\cdot}22_5$	$-0{\cdot}035$
$3{\cdot}05$	$-2{\cdot}29$	$-0{\cdot}74$	—	—	—
$0{\cdot}42_5$	$-0{\cdot}32$	$-0{\cdot}10_5$	$0{\cdot}43_5$	$-0{\cdot}35$	$-0{\cdot}08_5$
$0{\cdot}15_5$	$-0{\cdot}12$	$-0{\cdot}38$	$0{\cdot}16$	$-0{\cdot}13$	$-0{\cdot}032$
$1{\cdot}21$	$-0{\cdot}77$	$-0{\cdot}44$	$1{\cdot}3$	$-0{\cdot}89$	$-0{\cdot}41$
$0{\cdot}57$	$-0{\cdot}36_5$	$-0{\cdot}20_5$	$0{\cdot}58_5$	$-0{\cdot}4$	$-0{\cdot}18$
$0{\cdot}21$	$-0{\cdot}13_5$	$-0{\cdot}076$	$0{\cdot}21_5$	$-0{\cdot}14_5$	$-0{\cdot}06$
$9{\cdot}0$	$-5{\cdot}14$	$-4{\cdot}27$	$11{\cdot}2$	$-6{\cdot}39$	$-4{\cdot}81$
$0{\cdot}6$	$-0{\cdot}33$	$-0{\cdot}27_5$	$0{\cdot}61$	$-0{\cdot}35$	$-0{\cdot}26$
$0{\cdot}22$	$-0{\cdot}11$	$-0{\cdot}099$	$0{\cdot}22$	$-0{\cdot}13$	$-0{\cdot}09$
$6{\cdot}55$	$-3{\cdot}38$	$-2{\cdot}76$	$7{\cdot}65$	$-3{\cdot}99$	$-3{\cdot}66$

$C_1 = \left[F \right] \left[(\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1) \right]$, $C_2 = \left[F \right] \left[1{\cdot}1\ (\sigma_2 - \sigma_3) - (\sigma_1 - \sigma_2) \right]$,

$C_3 = \left[F \right] \left[(\sigma_3 - \sigma_1) - 1{\cdot}1\ (\sigma_2 - \sigma_3) \right]$ where $F = \left[A \left\{ \Sigma (\sigma_1 - \sigma_2)^2 \right\}^{0.215} + B \left\{ \Sigma\ (\sigma_1 - \sigma_2)^2 \right\}^5 \right]$, $A = 7{\cdot}8 \times 10^{-6}$, $B = 1{\cdot}5 \times 10^{-24}$

however, is not a conclusive test of isotropy as at least one type of anisotropy can give the same distribution of creep rates between the three principal directions in pure tension as in a state of isotropy. Again the material may be isotropic in one range of stresses, but anisotropic at higher stresses. Nevertheless if this test is fulfilled it is obvious that the chances of complete isotropy occurring generally are considerably enhanced.

The degree of isotropy may further be tested by a plot of the experimental values of the ratios $\frac{-\sigma_2}{(\sigma_1 - \sigma_3)}$ against $\frac{-C_2}{C_1}$. The experimental points can then be judged in

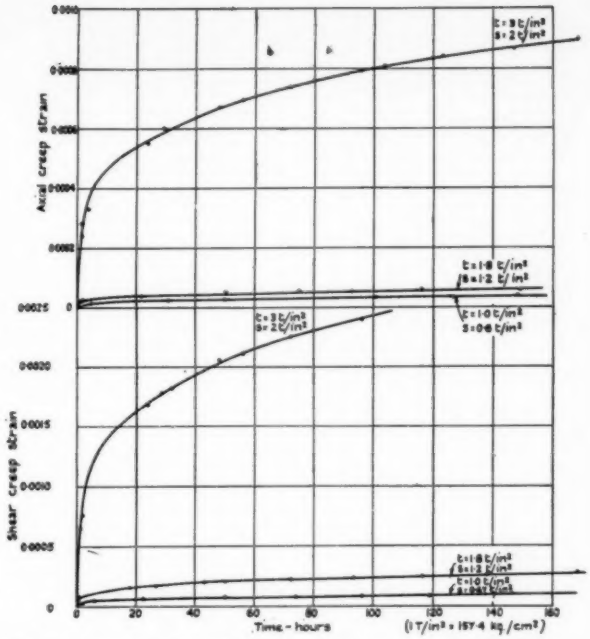


Fig. 5.—Creep-strain/time curves for the stress ratio $t/s = 1{\cdot}5$ at 20° C.

relation to curves for this particular plot corresponding to known isotropic forms of equation. These plots are shown in Fig. 8 for 20° C. and for 50° C.

In Fig. 8 the experimental points at 20° C. corresponding to moderate and lower stresses are compared with a curve corresponding to the known isotropic form of creep rate-stress relation

$$C_1 = A \left[(\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1) \right] \quad \text{etc.}$$

and also with a curve corresponding to a very slightly anisotropic form of relation given by the equations,

$$C_1 = A \left[(\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1) \right]$$

$$C_2 = A \left[1{\cdot}1\ (\sigma_2 - \sigma_3) - (\sigma_1 - \sigma_2) \right]$$

$$C_3 = A \left[(\sigma_3 - \sigma_1) - 1{\cdot}1\ (\sigma_2 - \sigma_3) \right]$$

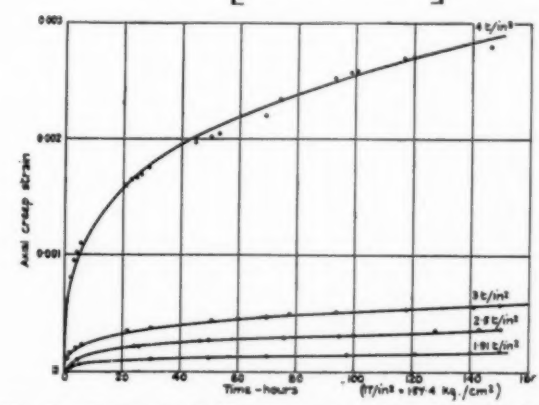


Fig. 6.—Creep-strain/time curves under pure tension stresses at 50° C.

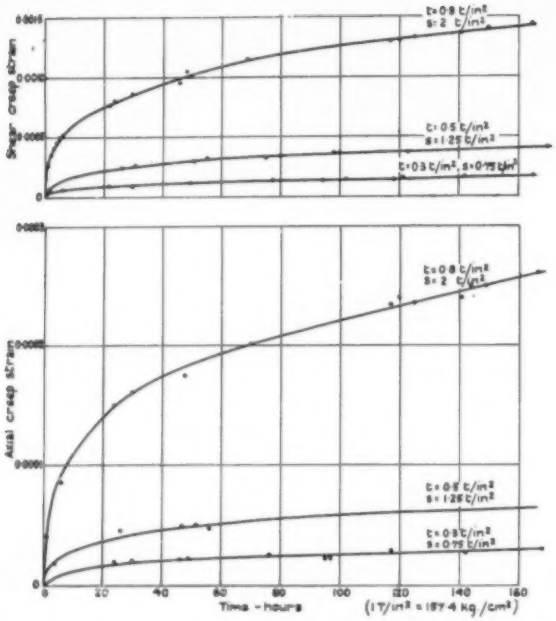


Fig. 7.—Creep-strain/time curves for the stress ratio s/t = 2·5 at 50° C.

Evidently the experimental points are well disposed between these two lines and it is evident that at this temperature, for moderate and low stresses, the degree of anisotropy is not greater than that slight degree expressed by the equation given above. The state of affairs for higher stresses will be indicated in a later paragraph both for this temperature and also for the higher temperature of 50° C.

Turning to the case of the moderate and lower stresses at 50° C., the experimental points are compared in Fig. 8 with the curve corresponding to the isotropic form of creep-rate/stress relations

$$C_1 = A \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1) \right] \quad \text{etc.}$$

and also with the curves corresponding with the two slight degrees of anisotropy expressed by the two sets of equations :

(*a*)
$$C_1 = A \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1) \right]$$
$$C_2 = A \left[1{\cdot}1\,(\sigma_2-\sigma_3) - (\sigma_1-\sigma_2) \right]$$
$$C_3 = A \left[(\sigma_3-\sigma_1) - 1{\cdot}1\,(\sigma_2-\sigma_3) \right]$$

and (*b*)
$$C_1 = A \left[(\sigma_1-\sigma_2) - 1{\cdot}1\,(\sigma_3-\sigma_1) \right]$$
$$C_2 = A \left[(\sigma_2-\sigma_3) - (\sigma_1-\sigma_2) \right]$$
$$C_3 = A \left[1{\cdot}1\,(\sigma_3-\sigma_1) - (\sigma_2-\sigma_3) \right]$$

It appears evident that the experimental points are disposed between the curve corresponding to the isotropic form, and the form (b) ; if anything, the form (b) corresponds the more closely. The inference is thus that some slight degree of anisotropy may be present at this temperature. It will be shown, however, in a later paragraph, that the deviation of the experimental points from the relatively simple form :

$$C_1 = A \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1) \right] \text{ etc.}$$

may be explained on other grounds than those of anisotropy. Again the higher stresses are given special consideration later.

Consideration of the Behaviour of the Magnesium Alloy at 20° C.

In the earlier papers[15,16] consideration was given to the forms of creep-rate/stress relations suggested by the various theoretical treatments which have been put forward. It was shown that such experimental work as had been performed suggested that either equations of the form :

$$C_1 = F \left[\Sigma (\sigma_1-\sigma_2)^2 \right] \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1) \right] \quad \text{etc.}$$

(where F is a function)

(special cases of which were suggested by Odquvist, Marin, Soderberg and Nadai) or equations of the form

$$C_1 = F \left[(\sigma_1-\sigma_2)^2 \right] \left[(\sigma_1-\sigma_2)^n - (\sigma_3-\sigma_1)^n \right] \quad \text{etc.}$$

(a special case of which was suggested by R. W. Bailey), were reasonably representative of experimental results currently existing.

It was also noted that the two varieties of equations mentioned above were special cases of the very general equations suggested by Prager,

$$\int (J_2, J_3^2) \left[p(J_2, J_3^2)\, J_2\, (S^2 - \tfrac{2}{3} J_2 I) + q\,(J_2, J_3^2) S \right]$$

where C is the creep rate tensor, S the stress deviator tensor, of the principal values, S_1, S_2, S_3, $J_2 = \frac{1}{2}\,(\Sigma S_1^2)$, $J_3 = \frac{1}{2}\,(\Sigma S_1^3)$, p and q are polynomials in J_2 and J_3^2, f is a function of J_2 and J_3, and $T = S^2 - \frac{2}{3} J_3 I$.

The functions f and F may, of course, assume various forms, but in most instances, have been of the nature of power functions. However, other forms are possible and in analysing experimental results it is necessary to discriminate between the various possible forms of creep-rate/stress equations to decide which particular variety best fits the data.

In the earlier papers[15,16] the means of comparison was (for reasons stated in these two papers) upon the basis of the shear stress and strain in the octahedral plane. In particular this type of plot offers a direct means of testing the applicability of the Hencky criterion of plastic strain to the current state of creep strain.

Accordingly, for the results at 20° C., plots were made of various functions of the octahedral shear stress against either the octahedral sheer creep rate, or of the ratio of octahedral shear creep rate to the octahedral shear stress. These plots illustrated the applicability or otherwise of various types of creep-rate/stress relations. In view of the appreciable number of these plots it has been thought necessary only to illustrate the plot which most reasonably and simply represented the results.

This particular plot appeared to be that of log. octahedral stress σ_o, against log. octahedral creep rate of C_o, and is shown in Fig. 9. It will be seen that the

experimental points, corresponding to the various stress systems, are reasonably well disposed around one general curve, thus indicating that the Hencky theory, which postulates that the octahedral strain is a definite function of the octahedral stress of the system, is a reasonably good approximation at this temperature. The curve of Fig. 9 is closely linear in its lower range of stress and therefore suggests that for this material and temperature the dependence of creep rate on stress is of the nature of a power function for low and moderate stresses. At higher stresses it appears that a more complex relation exists.

Considering in the first place the lower range of stresses, it may be stated that the general type of principal plane equations which correspond with a power function relation of creep rate to stress is

$$(1)\ C_1 = A\left[\Sigma(\sigma_1-\sigma_2)^2\right]^m\left[(\sigma_1-\sigma_2)^n - (\sigma_3-\sigma_1)^n\right] \quad \text{etc.}$$

which includes the special cases where $n = 1$ or $m = 0$.

The octahedral stress and strain corresponding to these equations are of course given by the relations

$$\sigma_o = {}^1/_3\ \sqrt{(\sigma_1-\sigma_2)^2} \quad \text{and}$$

$$C_o = {}^2/_3\ \sqrt{(C_1-C_2)^2}$$

and it is the logarithms of these latter functions which are plotted in Fig. 9.

It is shown in the Appendix that, on theoretical grounds, an isotropic material obeying the Hencky criterion would be expected, if showing a relation of general type (1), to conform with a value of $n = 1$ or 3. Variations from these values must therefore be in virtue of incomplete correspondence or entire disagreement with the Hencky criterion or in virtue of some degree of anisotropy. In the former case equations of the general Prager type or more simple Bailey type may be needed to represent the results, while in the latter anisotropic variations of the von Mises-St. Venant type of equation or even of the Bailey type may be required.

Now the linear portion of the curve of Fig. 9 has a slope of value 2. Assuming complete isotropy and correspondence with the Hencky criterion this value corresponds with principal plane equations of the type

Fig. 9.—Log. stress/log. creep rate curves for the octahedral plane.

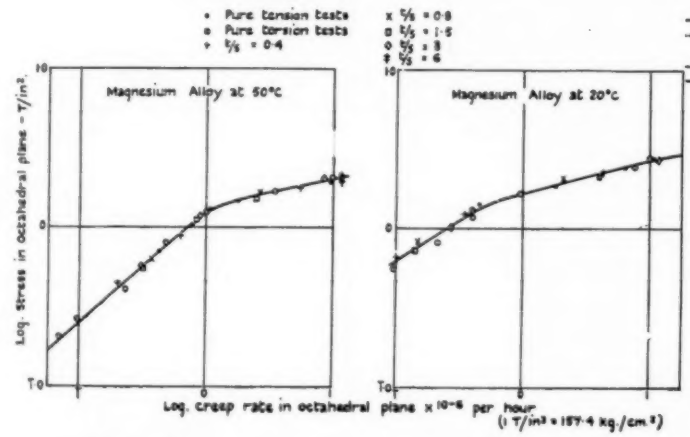
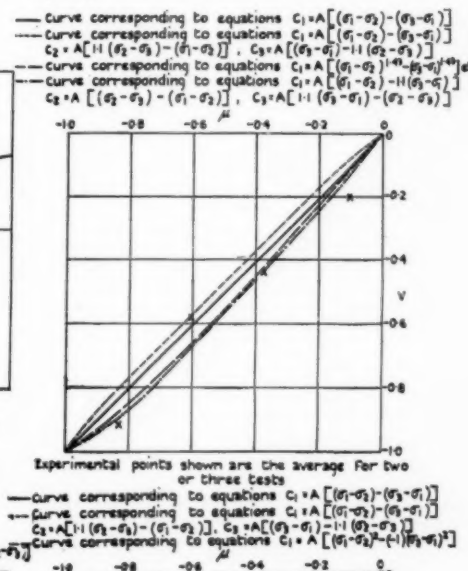


Fig. 11.—Relation at 50° C. between $\mu = 2\,\frac{\sigma_3-\sigma_2}{\sigma_1-\sigma_2} - 1$, $\nu = 2\,\frac{C_3-C_2}{C_1-C_2} - 1$ where $\sigma_2 = 0$ in all tests



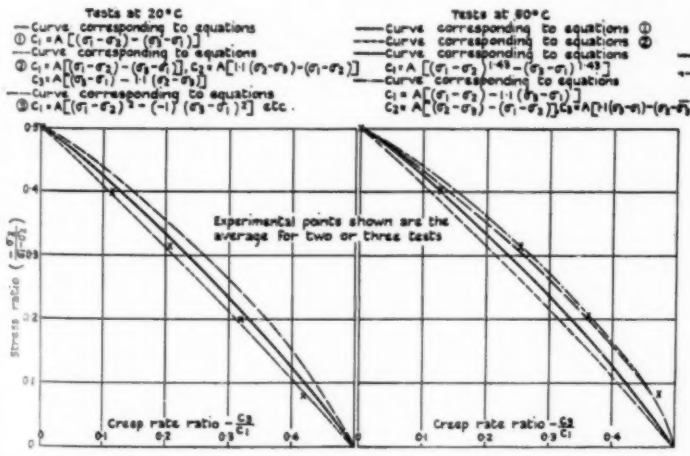


Fig. 8.—Relations between stress ratio $\frac{\sigma_2}{\sigma_1-\sigma_2}$ and creep rate ratio $\frac{-C_2}{C_1}$

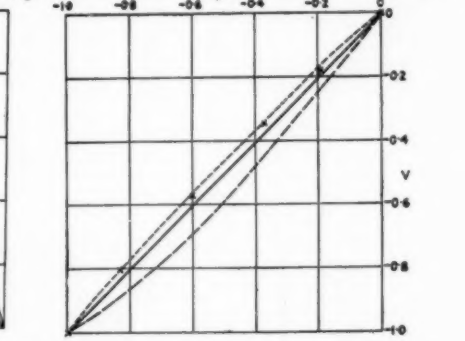


Fig. 10.—Relation at 20° C. between $\mu = 2\,\frac{\sigma_3-\sigma_2}{\sigma_1-\sigma_2} - 1$, $\nu = 2\,\frac{C_3-C_2}{C_1-C_2} - 1$ where $\sigma_2 = 0$ in all tests

$$C_1 = A\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{0.5}\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right]$$

There is some slight scatter of the experimental points about the line although this scatter is symmetrically disposed and obviously the above equation must give a good arithmetical representation of the general trend of the results.

Nevertheless, it is advisable to consider alternative forms of representation which, in view of possible departures from the Hencky criterion or complete isotropy, may represent the results within the accuracy of the experiments.

Initially reference to Fig. 8 in which the functions $\frac{-C_2}{C_1}$ and $\frac{-\sigma_2}{(\sigma_1-\sigma_3)}$ are compared, as a means of indicating the degree of isotropy attained, gives some pointer to the type of equation most reasonably representing the results. In this figure the experimental points are compared with curves of $\frac{C_3}{C_1}$ against $\frac{-\sigma_2}{(\sigma_1-\sigma_3)}$ corresponding to the isotropic Von Mises-St. Venant equations.

$$C_1 = A\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{0.5}\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right] \text{ etc.}$$

secondly, to a very slightly anisotropic form of this equation

$$C_1 = A\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right]$$

$$C_2 = A\left[1{\cdot}1\,(\sigma_2-\sigma_3)-(\sigma_1-\sigma_2)\right]$$

$$C_3 = A\left[(\sigma_3-\sigma_1)-1{\cdot}1\,(\sigma_2-\sigma_3)\right]$$

and thirdly with the Bailey type of equation which, while isotropic in form, does not correspond with the Hencky criterion. This latter equation is

$$C_1 = A\left[(\sigma_1-\sigma_2)^2-(-1)(\sigma_3-\sigma_1)^2\right] \text{ etc.}$$

Evidently, Fig. 8 indicates that the experimental results lie between the isotropic and anisotropic forms of the Von Mises-St. Venant equations, the degree of anisotropy being less than that indicated by the arithmetical constant 1·1, and are not represented by the curve corresponding to the Bailey equation.

Additional evidence in this matter may be sought in Table I and Fig. 10. In Table I values of C_a/C_c and t/3s are compared. For complete isotropy and correspondence with the Von Mises-St. Venant equation, these values should be equal for all stress systems[16]. Again in Fig. 10 the Lode stress and strain criteria

$$\mu = \frac{2(\sigma_2-\sigma_3)}{(\sigma_1-\sigma_4)} - 1$$

and

$$\nu = \frac{2(C_2-C_3)}{(C_1-C_3)} - 1$$

are compared. For complete isotropy and correspondence with the Hencky criterion, these functions should have equal values for all stress systems. In Table I it will be seen that, for all test points corresponding to lower and middle stress values, the agreement between C_a/C_c and t/3s is very good except in the case of the test at 1·8 tons/sq.in. tension, and 1·2 tons/sq.in. torsion where the value of C_a/C_c is 0·42 as compared with 0·50 for t/3s. As, however, this particular point is immediately at the commencement of the curved portion of the characteristic curve in Fig. 9 it is more than likely that some anisotropy occurs here which is not characteristic of the remainder of the linear portion of Fig. 9.

Again in Fig. 10 the experimental points are compared with curves for μ and ν corresponding to the equations

(a) $C_1 = A\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right]$ etc. where $A = A\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{0.5}$ in this case

(b) $C_1 = A\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right]$

$C_2 = A\left[1{\cdot}1\,(\sigma_2-\sigma_3)-(\sigma_1-\sigma_2)\right]$

$C_3 = A\left[(\sigma_3-\sigma_1)-1{\cdot}1\,(\sigma_2-\sigma_3)\right]$

and the Bailey type

$$C_1 = A\left[(\sigma_1-\sigma_2)^2-(-1)(\sigma_3-\sigma_1)^2\right] \text{ etc.}$$

The evidence of Fig. 8 is here confirmed. It is again evident that the experimental points lie between equations (a) and (b), on the whole being in this case closer to (b), and are not represented by the Bailey equation.

In general, therefore, for lower and moderate stresses at this temperature, we may conclude that the behaviour of the material is well represented by the Von Mises-St. Venant equations

$$C_1 = A\left[(\sigma_1-\sigma_2)^2\right]^{0.5}\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right]$$

where $A = 1{\cdot}39 \times 10^{-8}$

some very slight degree of anisotropy possibly being present however. From a practical point of view, of course, the arithmetical values of principal creep rates given by the Von Mises-St. Venant and Bailey equations (here using $A = 2\times10^{-8}$) are not widely different, either from each other or from the experimental values. These various sets of values are compared in Table I.

Turning now to consideration of the higher ranges of stress at 20° C. as shown in Fig. 9, it will be noted that the curvature of the curve changes from a slope of 2 to a slope of approximately 7. The change is relatively smooth, and immediately suggests that the curve may well be represented by the sum of power functions. This proved to be the case, and the actual curve shown in Fig. 9 corresponds to the octahedral equivalent of either of the principal plane equations

$$C_1 = \left\{A\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{0.5} + C\left[\Sigma(\sigma_1-\sigma_2)^2\right]^3\right\}\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right] \text{ etc.}$$

where $A = 1{\cdot}39 \times 10^{-8}$, and $C = 2 \times 10^{-12}$

or, alternatively,

$$C_1 = \left\{A + C\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{2.5}\right\}\left[(\sigma_1-\sigma_2)^2-(-1)(\sigma_3-\sigma_1)^2\right]$$

where $A = 2 \times 10^{-8}$, and $C = 2{\cdot}7 \times 10^{-12}$

In view of the previous discussion of the equations corresponding to the linear portion of the curve in Fig. 9,

a preference must be expressed for the equations

$$C_1 = \left\{ A \left[\Sigma (\sigma_1 - \sigma_2)^2 \right]^{0.5} + C \left[\Sigma (\sigma_1 - \sigma_2)^2 \right]^3 \right\} \left[(\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1) \right] \text{ etc.}$$

These equations of course deteriorate into

$$C_1 = A \left[\Sigma (\sigma_1 - \sigma_2)^2 \right]^{0.5} \left[(\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1) \right]$$

At moderate and low stresses.

Examination of the results in Table I, however, indicates that while the general order of the principal creep rates given by these equations is correct, the distribution of creep between the lateral directions differs from that of the experimental values.

It is noted that for the latter values at high stresses, the tendency is for the major and secondary creep rates

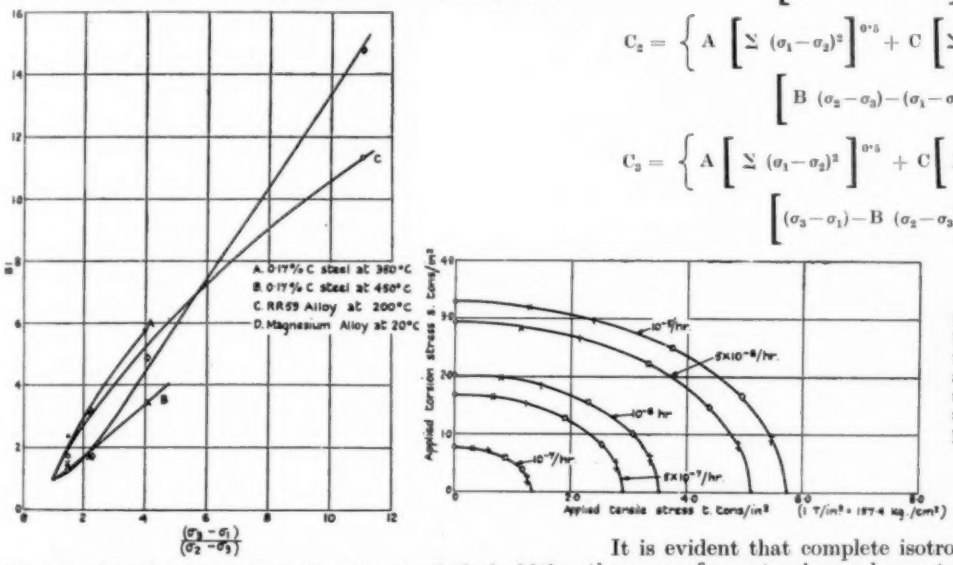


Fig. 12.—Combined stress creep tests at relatively high strains on various materials relation between the stress ratio $\frac{\sigma_3 - \sigma_1}{\sigma_2 - \sigma_3}$ and the values of the constant B, in equations :

$$C_1 = F \left[\Sigma (\sigma_1 - \sigma_2)^2 \right] \left[(\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1) \right]$$

$$C_2 = F \left[\Sigma (\sigma_1 - \sigma_2)^2 \right] \left[B (\sigma_2 - \sigma_3) - (\sigma_1 - \sigma_2) \right]$$

$$C_3 = F \left[\Sigma (\sigma_1 - \sigma_2)^2 \right] \left[(\sigma_3 - \sigma_1) - B (\sigma_2 - \sigma_3) \right]$$

to approach numerical equality, while the wall thickness creep rate tends to zero. This tendency has been noted in similar circumstances for other materials. It is evident that the material behaves in these tests essentially as in pure torsion tests, in which the axes of strain are those of the inital principal axes of stress of the system. These circumstances have been represented in the case of previous materials by equations of the type

$$C_1 = F \left\{ (\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1) \right\}$$

$$C_2 = F \left\{ B (\sigma_2 - \sigma_3) - (\sigma_1 - \sigma_2) \right\}$$

$$C_3 = F \left\{ (\sigma_3 - \sigma_1) - B (\sigma_2 - \sigma_3) \right\}$$

where F is a function of $[\Sigma (\sigma_1 - \sigma_2)^2]$ and B is an arithmetical constant.

Similar equations well represented the results in this case. B having values as follows

s/t	∞	2·5	1·25	0·67	0·33
B	1	1·3	1·69	4·8	14·8

thus B increases with decreasing value of s/t and apparently tends towards the value $\frac{(\sigma_3 - \sigma_1)}{(\sigma_2 - \sigma_3)}$. Thus the general equations for the whole stress range in the present case are

$$C_1 = \left\{ A \left[\Sigma (\sigma_1 - \sigma_2)^2 \right]^{0.5} + C \left[\Sigma (\sigma_1 - \sigma_2)^2 \right]^3 \right\} \left[(\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1) \right]$$

$$C_2 = \left\{ A \left[\Sigma (\sigma_1 - \sigma_2)^2 \right]^{0.5} + C \left[\Sigma (\sigma_1 - \sigma_2)^2 \right]^3 \right\} \left[B (\sigma_2 - \sigma_3) - (\sigma_1 - \sigma_2) \right]$$

$$C_3 = \left\{ A \left[\Sigma (\sigma_1 - \sigma_2)^2 \right]^{0.5} + C \left[\Sigma (\sigma_1 - \sigma_2)^2 \right]^3 \right\} \left[(\sigma_3 - \sigma_1) - B (\sigma_2 - \sigma_3) \right]$$

Fig. 13.—Relation between applied tensile stress and applied torsion stress to produce specific octahedral plane creep rates at 20° C.

It is evident that complete isotropy is preserved for the cases of pure tension and pure torsion (since for this case B = 1). This is in accordance with the experimentally observed fact that no axial strain occurred in pure torsion tests.

In Fig. 12 the variation of the arithmetical constant B with the ratio $\frac{(\sigma_3 - \sigma_1)}{(\sigma_2 - \sigma_3)}$ is shown for several materials including the current material at 20° C.

Obviously for this type of anisotropy any relations involving the *major* principal creep rates will be the same as for a case of complete isotropy.

In the earlier papers[15,16] it was shown that the combinations of tensile stress t and shear stress s required to produce a specific octahedral creep rate are given by the elliptical equation

$$\frac{t^2}{T^2} + \frac{s^2}{S^2} = 1 \qquad \text{where} \quad T = \sqrt{3}\, S,$$

and T is the pure tensile stress producing this octahedral creep rate when applied alone, and S is the corresponding shear stress. This relation enables principal, axial and shear creep rates for any combined stress system to be computed from plain tensile or torsion creep data, in the case of any isotrop c material in which the log. stress/log. creep-rate curve is linear and the Hencky criterion is obeyed. In Fig. 13 the ellipses corresponding to this

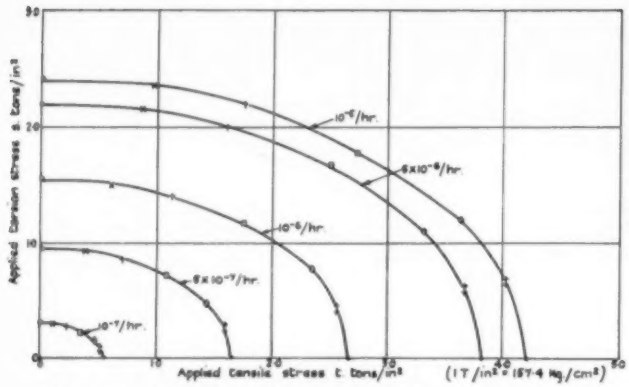


Fig. 14.—Relation between applied tensile stress and applied torsion stress to produce specific octahedral plain creep rates at 50° C.

relation are shown for several values of octahedral creep rate.

In Figs. 15 and 17 two sets of curves are shown which are useful from the point of view of the designer. Firstly, in Fig. 15, values of log. major principal creep rates, for specific values of major principal stresses, are shown for various ratios of the major and one secondary principal stress, the other principal stress being zero in all cases. In this figure, values of the major principal stress σ_1 are combined with various values of σ_2 ranging from $\sigma_2 = +\sigma_1$, to $\sigma_2 = -\sigma_1$ and having $\sigma_3 = 0$ in all cases. The creep rates in question are computed from the experimentally derived equations.

$$C_1 = \left\{ A \left[\Sigma\,(\sigma_1-\sigma_2)^2 \right]^{0.5} + C \left[\Sigma\,(\sigma_1-\sigma_2)^2 \right]^3 \right\} \left[(\sigma_1-\sigma_3)-(\sigma_3-\sigma_1) \right] \quad \text{etc.}$$

where $A = 1{\cdot}39 \times 10^{-8}$ and $C = 2 \times 10^{-12}$

From Fig. 15, by interpolation of values of σ_1 along the ordinates intersecting the horizontal axis at some specific value of the major principal creep rate, a series of curves may be obtained giving for a series of ratios σ_1/σ_2, the values of σ_1 corresponding to a given specific major principal creep rate. These curves are shown in Fig. 17.

Consideration of the Behaviour of the Magnesium Alloy at 50° C.

The various possible types of creep rate-stress relation have been stated in the previous paragraph and also the means of choosing the most appropriate type of equation to represent the experimental result. These statements of course, apply equally to the tests at 50° C.

Again at this temperature it was found that the most simple and representative plot was of log. octahedral stress σ_0 against log. octahedral creep rate C_0. This plot is shown in Fig. 9 and it will be observed that in this case the experimental points are closely disposed round one common curve apparently indicating that the material closely obeys the Hencky criterion of plastic strain.

It will be noted that at moderate and low ranges of stress, the log. stress/log. creep-rate relation is linear, indicating the dependence of the creep-rate upon a simple power function of stress. The curve departs smoothly from linearity at higher stresses and, presumably, a more complex relation between stress and creep strain must arise.

Considering in the first place the moderate and lower ranges of stress, the linearity of the log. stress/log. creep-rate curve must be associated with a principal plane equation of general type.

$$C_1 = A \left[\Sigma\,(\sigma_1-\sigma_2)^2 \right]^m \left[(\sigma_1-\sigma_2)^n - (\sigma_3-\sigma_1)^n \right]$$

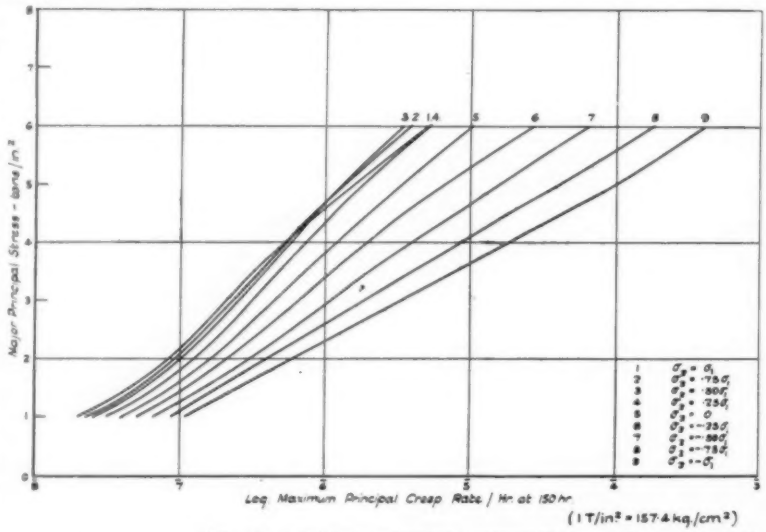


Fig. 15.—Major principal stress/log. major principal creep rate relations at 20 °C. for various values of the minor principal stress based on the equation :

$$C_1 = \left\{ A \left[\Sigma\,(\sigma_1-\sigma_2)^2 \right]^{0.5} + B \left[\Sigma\,(\sigma_1-\sigma_2)^2 \right]^3 \right\} \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1) \right]$$

where $A = 1{\cdot}39 \times 10^{-8}$, $B = 2 \times 10^{-12}$ $\sigma_3 = 0$

from which octahedral plane equations may be computed by use of the relations

$$\sigma_0 = \tfrac{1}{3}\sqrt{(\sigma_1-\sigma_2)^2} \quad \text{and} \quad C_0 = \tfrac{2}{3}\sqrt{(C_1-C_2)^2}$$

It will be noted upon inspection that the linear curve in Fig. 9 has a slope of 1·43. Thus equations of either of the types

$$C_1 = \left\{ A \left[\Sigma\,(\sigma_1-\sigma_2)^2 \right]^{\cdot 215} \right\} \left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1) \right] \quad \text{etc.}$$

or

$$C_1 = A \left[(\sigma_1-\sigma_2)^{1\cdot 43} - (\sigma_3-\sigma_1)^{1\cdot 43} \right] \quad \text{etc.}$$

may be used to represent the experimental results at moderate and lower stresses. Some further evidence must be sought to give a decision between these two types of equation.

The same criteria may be used as in the case of the tests at 20° C., viz. the identity or otherwise of the ratios $t/3$, or C_s/C_c and the relations between the two sets of

variables

$\frac{C^3}{C^1}$ and $\frac{-\sigma_2}{(\sigma_1-\sigma_3)}$ and $\mu = \frac{2(\sigma_3-\sigma_2)}{(\sigma_1-\sigma_3)} - 1$ and $\nu = \frac{2(C_3-C_2)}{(C_1-C_3)} - 1$

The values of the ratios t/3s and C_a/C_c are given in Table II. It will be seen that the agreement is in most cases good (<6% difference), although not quite so good as at 20° C. One case shows a difference of about 10%. These differences, such as they are, may be due to departure of the exponent in the deviator term of the stress/creep-rate from unity, or to slight degrees of anisotropy. In neither case would the divergence be expected to be very appreciable however.

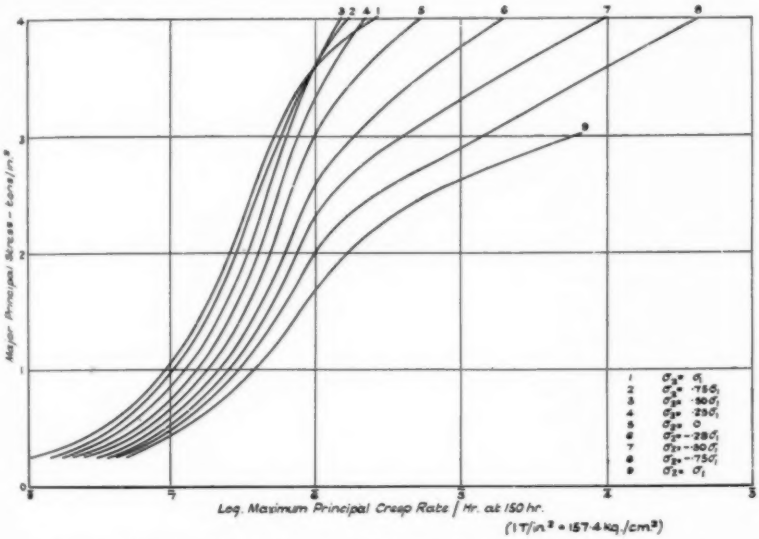


Fig. 16.—Major principal stress/log. major principal creep rate relations at 50° C. for various values of the minor principal stress based on the equation :

$$C_1 = \left\{ A \left[\Sigma\ (\sigma_1-\sigma_2)^2 \right]^{0\cdot215} + B \left[\Sigma\ (\sigma_1-\sigma_2)^2 \right]^5 \right\} \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1) \right]$$

where $A = 7\cdot8 \times 10^{-8}$, $B = 1\cdot5 \times 10^{-14}$, $\sigma_3 = 0$

Turning to Fig. 8 in which values of $\frac{-C_3}{C_1}$ are contrasted with $\frac{-\sigma_2}{(\sigma_1-\sigma_3)}$ we note that here the experimental values are compared with curves of $\frac{-C_3}{C_1}$ and $\frac{-\sigma_2}{(\sigma_1-\sigma_3)}$ corresponding to the following equations

(a) $C_1 = A \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1) \right]$ etc.

(b) $C_1 = A \left[(\sigma_1-\sigma_2) - 1\cdot1\ (\sigma_3-\sigma_1) \right]$

$C_2 = A \left[(\sigma_2-\sigma_3) - (\sigma_1-\sigma_2) \right]$

$C_3 = A \left[1\cdot1\ (\sigma_3-\sigma_1) - (\sigma_2-\sigma_3) \right]$

(c) $C_1 = A \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1) \right]$

$C_2 = A \left[1\cdot1\ (\sigma_2-\sigma_3) - (\sigma_1-\sigma_2) \right]$

$C_3 = A \left[(\sigma_3-\sigma_1) - 1\cdot1\ (\sigma_2-\sigma_3) \right]$

(d) $C_1 = A \left[(\sigma_1-\sigma_2)^{1\cdot43} - (\sigma_3-\sigma_1)^{1\cdot43} \right]$ etc. (Bailey)

Evidently the experimental points appear to be most generally represented by either of the curves corresponding to equations (b) and (d).

Finally, consider the relations between the Lode variables μ and ν shown in Fig. 11. Here the experimental points are again contrasted with the curves corresponding to the four equations above mentioned, and it is very difficult to decide which equation most nearly represents the data. If anything equations (b) and (d) again may be regarded as most suitable.

We may, therefore, say that in this instance, it is evident that some very slight anisotropy or slight deviation from compliance with the Hencky theory may exist, although the closeness of experimental points of all stress systems to one general curve shown in Fig. 9 suggests that agreement is close in the latter case. However, under the circumstances it may be suggested that either of the equations

$$C_1 = \left\{ A \left[\Sigma\ (\sigma_1-\sigma_2)^2 \right]^{\cdot215} \right\} \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1) \right]$$

where $A = 7\cdot8 \times 10^{-8}$

or $C_1 = A \left\{ \Sigma\ (\sigma_1-\sigma_2)^{1\cdot43} - (\sigma_3-\sigma_1)^{1\cdot43} \right\}$

where $A = 8\cdot9 \times 10^{-8}$

may be utilised to express the experimental results. In Table II the experimental results are compared with the two sets of values corresponding (at low and moderate stresses) with the above two sets of equations.

Turning now to the case of the higher range of stresses, we note that in Fig. 9 the slope of the curve in these regions changes from that of the linear portion to a value of about eleven. This suggests at once that equations of the two general forms (principal planes)

$$C_1 = \left\{ A \left[\Sigma\ (\sigma_1-\sigma_2)^2 \right]^{\cdot215} + B \left[\Sigma\ (\sigma_1-\sigma_2)^2 \right]^5 \right\} \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1) \right]$$

or $C_1 = \left\{ A + B \left[\Sigma\ (\sigma_1-\sigma_2)^2 \right]^{4\cdot75} \right\} \left[(\sigma_1-\sigma_2)^{1\cdot43} - (\sigma_3-\sigma_1)^{1\cdot43} \right]$

might well be used to express the experimental results. In actual fact the curve shown corresponds to the octahedral plane form of both of the above equations where for the first equation

$$A = 7{\cdot}8 \times 10^{-8},\ B = 1{\cdot}5 \times 10^{-14}$$

and for the second equation

$$A = 8{\cdot}9 \times 10^{-8} \text{ and } B = 1{\cdot}41 \times 10^{-14}$$

The creep rates corresponding with these equations are shown in Table II. It will be observed that while the magnitudes of the computed principal creep rates correspond well with the experimental values, it is nevertheless true, in some cases, that the distribution of creep between the two secondary directions is not that shown by the experiments in the combined stress tests.

It is evident from Table II that, compared with the theoretical values in the experimental results, C_2 tends to decrease and C_3 to increase while for the extreme case of $t/s = 6$, C_2 has become very small indeed and C_3 tends to numerical equality with C_1. These tendencies are in direct contrast to those exhibited by the material at 20° C. and to the behaviour of all the materials previously tested (all these were cubic lattice materials). The tendency is for wall thickness strain to take place at the expense of secondary lateral strain. It appears possible that, for relatively high strains at this temperature, the crystal basal plane may become oriented in the plane of wall thickness giving easier slip in this plane than in the other lateral direction.

Analysis indicates that this mode of deformation requires a different and more complex set of equations to represent it than were required for the anisotropic creep occurring at high stresses in other materials or in the present material at 20° C.

These equations appear to be of the general form

$$C_1 = (F)\left[A_1\ (\sigma_1-\sigma_2) - B_1\ (\sigma_3-\sigma_1)\right]$$

$$C_2 = (F)\left[(\sigma_2-\sigma_3) - A_1\ (\sigma_1-\sigma_2)\right]$$

$$C_3 = (F)\left[B_1\ (\sigma_3-\sigma_1) - (\sigma_2-\sigma_3)\right]$$

but the precise degree of anisotropy varies with the stress system imposed, A_1 and B_1 having variable values. These are as follows :—

Value t/s	0·4	0·8	3	6*
A_1	0·88	0·61	0·63$_5$	0·03
B_1	1·21	1·57	1·4	2

These values, however, are always such that

$$A_1\ (\sigma_1-\sigma_2) - B_1\ (\sigma_3-\sigma_1) = (\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)$$

It is evident that B_1 increases at the expense of A_1 at a moderate rate up to $t/s = 3$, but subsequently, at $t/s = 6$, A_1 has virtually become zero and $C_1 = -C_3$ with C_2 zero, i.e., the secondary creep is largely in the direction of wall thickness. It appears that pure torsion is a limiting case of this system when $A_1 = B_1 = 1$. The case of pure tension will in this system presumably show anisotropic distortion, drawing down being largely in wall thickness.

*It will be noted that in the case of a test, $t = 2{\cdot}1$ tons/sq. in., $s = 1{\cdot}4$ tons/sq. in., the material is isotropic, although the test falls in the higher stress range. This specimen however was taken from another billet.

As in the case of the present material at 20° C., the relation

$$\frac{t^2}{T^2} + \frac{s^2}{S^2} = 1$$

is shown for several values of the octahedral creep rate in Fig. 14.

In Fig. 16 the plot of maximum principal stress against log. major principal creep rate is shown for a variety of stress systems. The creep rates are based on the relation

$$C_1 = \left\{ A\left[\Sigma\ (\sigma_1-\sigma_2)^2\right]^{\cdot215} + B\left[\Sigma\ (\sigma_1-\sigma_2)^2\right]^5 \right\} \left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right]$$

This is the isotropic form of the relation, but since in the case of the anisotropic form

$$A_1\ (\sigma_1-\sigma_2) - B_1\ (\sigma_3-\sigma_1) = (\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)$$

the arithmetical values of the rates are the same as in the anisotropic form actually existing.

In Fig. 18 the variation of maximum principal stress with the ratio of secondary to major principal stress is given for a number of specific values of creep rates. These curves are obtained by interpolation in Fig. 16.

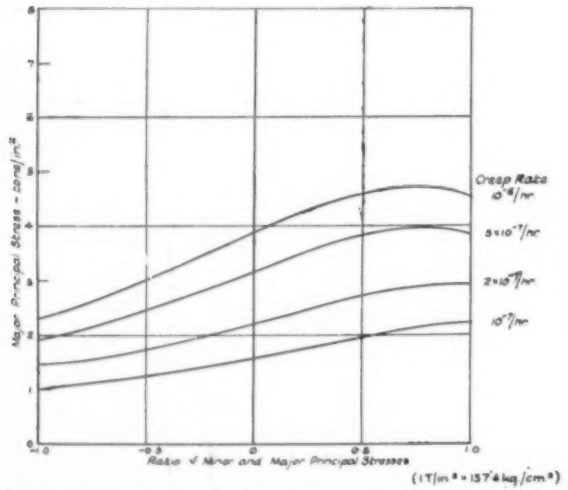


Fig. 17.—Major principal stresses to give various specific creep rates at 150 hours at 20° C. for various rates of minor to major principal stresses, the third principal stress being zero.

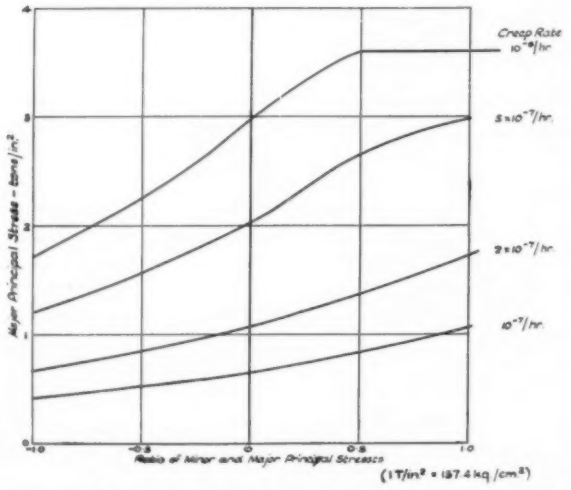


Fig. 18.—Major principal stresses to give various specific creep rates at 150 hours at 50° C. for various rates of minor to major principal stresses, the third principal stress being zero.

General Conclusions

(1) At low and moderate stresses the magnesium alloy behaves closely isotropically at 20° and 50° C. At higher stresses anisotropy occurs at both temperatures, possibly being associated with the relatively high degree of initial plastic strain at these stresses.

(2) Over the whole of the stress ranges investigated the material appeared to obey the Hencky, or shear-strain-energy, criterion of plastic strain.

(3) At moderate and low stresses the creep rate stress relations were well represented at 20° C. by equations of the type

$$C_1 = A \left[\Sigma(\sigma_1-\sigma_2)^2\right]^{0.5} \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] \text{ etc.}$$

and at 50° C. equally well by either of the two types of equation

$$C_1 = \left\{ A \left[\Sigma(\sigma_1-\sigma_2)^2\right]^{0.215} \right\} \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] \text{ etc.}$$

$$\text{or } C_1 = A \left[(\sigma_1-\sigma_2)^{1.43} - (\sigma_3-\sigma_1)^{1.43}\right]$$

(4) Over the whole range of stress the creep rate-stress relations appeared to be represented at 20° C. by equations of the type,

$$C_1 = \left\{ A \left[\Sigma\ (\sigma_1-\sigma_2)^2\right]^{0.5} + B \left[\Sigma\ (\sigma_1-\sigma_2)^2\right]^3 \right\} \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] \text{ etc.}$$

while at 50° C. they were represented by equations of type

$$C_1 = \left\{ A \left[\Sigma\ (\sigma_1-\sigma_2)^2\right]^{0.215} + B \left[\Sigma\ (\sigma_1-\sigma_2)^2\right]^5 \right\} \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] \text{ etc.}$$

At this temperature, however, an alternative form was

$$C_1 = \left\{ A + B \left[\Sigma\ (\sigma_1-\sigma_2)^2\right]^{4.79} \right\} \left[(\sigma_1-\sigma_2)^{1.43} - (\sigma_3-\sigma_1)^{1.43}\right]$$

At moderate and low stresses the above equations deteriorated into the equations given under (3) above.

(5) The anisotropy occurring at high stresses was such at 20° C. as to tend to equalise the values of major and minor creep rates and to render wall thickness creep approximately zero (as in a pure torsion test). These conditions can be represented by equations of the general type

$$C_1 = (F) \left[\Sigma\ (\sigma_1-\sigma_2)^2\right] \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right]$$

$$C_2 = (F) \left[\Sigma\ (\sigma_1-\sigma_2)^2\right] \left[B_1\ (\sigma_2-\sigma_3) - (\sigma_1-\sigma_2)\right]$$

$$C_3 = (F) \left[\Sigma\ (\sigma_1-\sigma_2)^2\right] \left[(\sigma_3-\sigma_1) - B_1\ (\sigma_2-\sigma_3)\right]$$

where B_1 is dependent on the applied stress system and exceeds unity in all cases except pure torsion. These equations correspond with a state of isotropy for pure tension and torsion which is in accordance with the noted experimental facts.

At 50° C., however, the anisotropy noted at high stresses is such as to tend to equalise the values of major and wall thickness creep rates and to render the minor lateral creep rate zero.

The conditions can be represented by the equations

$$C_1 = F \left[\Sigma\ (\sigma_1-\sigma_2)^2\right] \left[A_1\ (\sigma_1-\sigma_2) - B_1\ (\sigma_3-\sigma_1)\right]$$

$$C_2 = F \left[\Sigma\ (\sigma_1-\sigma_2)^2\right] \left[(\sigma_2-\sigma_3) - A_1\ (\sigma_1-\sigma_2)\right]$$

$$C_3 = F \left[\Sigma\ (\sigma_1-\sigma_2)^2\right] \left[B_1\ (\sigma_3-\sigma_1) - (\sigma_2-\sigma_3)\right]$$

where A_1 and B_1 are dependent on the applied stress system A_1 being less than unity, in all cases except pure torsion, and B_1 greater than unity.

BIBLIOGRAPHY

1 B. de St. Venant. Sur l'etablissement des equations des mouvements interviers opéres dans les corps solides ductiles au dela des limites ou l'elsticite pouver les remener à leur premier état. *Compt. Rendue* 70, p. 473, 1870.
2 Tapsell, H. J., and Johnson, A. E. Creep under Combined Tension and Torsion. *Engineering*, **150**, July, August, 1940.
3 Odquvist, F. K. A Theory of Creep under Combined Stresses. Proceedings Fourth International Congress of Applied Mechanics, p. 228 (1934), also Plasticitetsteon Royal Swedish Institute of Engineering Research, 1934.
4 Bailey, R. W. The Utilisation of Creep Test Data in Engineering Design. *Journal Institution of Mechanical Engineers*, **131**, p. 131 (1935), also *Engineering*, CXI, p. 595, 647 (1935).
5 Kanter, J. J. The Interpretation and Use of Creep Results. *Journal American Society of Metals*, **24**, p. 870 (1936).
6 Soderberg, C. R. The Interpretation of Creep Tests for Machine Design. *Trans. A.S.M.E.*, **58**, No. 8. p. 773 (November, 1936).
7 Marin, J. Design of Members subjected to Creep at High Temperatures. *J. App. Mech.*, **4**, No. 1 (March, 1937).
8 Nadai, A. On the Creep of Solids at Elevated Temperatures. *J. App. Phys.*, **8**, No. 6 (June, 1937).
9 Jamieson, J. An Investigation Relating to the Plastic Flow of Lead. Univ. of Michigan (1933).
10 Everett, F. L., and Clark, C. I. Report on Torsion Creep Tests for Comparison with Tension Creep Tests on a Carbon Molybdenum Steel. *Proc. A.S.T.M.*, **39**, p. 215–225 (1939).
11 Norton, F. H. Creep of Tubular Pressure Vessels. *Trans. A.S.M.E.*, **61**, No. 3 (1939) and Progress Report on Tubular Creep Tests. Presented 61st Annual Meeting, A.S.M.E., December, 1940.
12 Davies, E. A. Correlation of Test Results for Various Types of High Temperature Tests carried out for the Joint Research Committee, A.S.M.E. *Proc.* A.S.T.M., **39**, 1939.
13 Lode, W. Der Seinflub der mittleren Hauptspaning auf das Flieben der Metalle Forschungsarbeiten auf dem gebiete des ingenieur Wesens, No. 303 (1928).
14 Prager, W. Strain Hardening under Combined Stresses. *Journal of Applied Physics*, **16** (December, 1945).
15 Johnson, A. E. The behaviour of a Nominally Isotropic 0·17% Cast Carbon Steel under Combined Stress Systems at Elevated Temperatures. Part I. Creep Behaviour at 350, 450 and 550° C. J/T. 137. B.E.A.I.R.A., J/E. Committee, 1948.
16 Johnson, A. E. The Creep of a Nominally Isotropic Aluminium Alloy under Combined Stress Systems at Elevated Temperatures. D.S.I.R. Mech. Engineering Research Board. Properties and Mechanics of Materials Committee, P.M. 24, 1948.

Appendix

The nature of the creep rate-stress relations in the case of an isotropic material obeying the Hencky or shear-strain energy criterion of plastic strain.

Suppose the relations are such that the creep rate is a power function of the stress system. In its most simple form let this be :

$$C_1 = A \left[\tfrac{1}{2}\Sigma(\sigma_1-\sigma_2)^2\right]^m \left[(\sigma_1-\sigma_2)^n - (\sigma_3-\sigma_1)^n\right]$$

$$C_2 = A \left[\tfrac{1}{2}\Sigma(\sigma_1-\sigma_2)^2\right]^m \left[(\sigma_2-\sigma_3)^n - (\sigma_1-\sigma_2)^n\right]$$

$$C_3 = A \left[\tfrac{1}{2}\Sigma(\sigma_1-\sigma_2)^2\right]^m \left[(\sigma_3-\sigma_1)^n - (\sigma_2-\sigma_3)^n\right]$$

where $\sigma_1 > \sigma_3 > \sigma_2$

also let the materials obey the Hencky shear-strain energy criterion of plastic strain. When this is so, for equal values σ_o of the octahedral shear stress in tension and torsion, equal values of the octahedral creep rate γ_o will arise.

Now consider the two cases of tension and torsion:

(1) *Tension* Here let $\sigma_1 = t$, $\sigma_2 = \sigma_3 = 0$, $\frac{1}{2}\Sigma(\sigma_1-\sigma_2)^2 = t^2$

$C_1 = At^{2m}\left[2t^n\right] = 2At^{2m+n}$

$C_2 = -At^{2m+n}$

$C_3 = -At^{2m+n}$

Octahedral stress $\sigma_{ot} = {}^1/_3\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{\frac{1}{2}} = \sqrt{\frac{2}{3}}\,t$

Octahedral creep $C_{ot} = {}^2/_3\left[(C_1-C_2)^2\right]^{\frac{1}{2}} = 2\sqrt{2}\,At^{2m+n}$

(2) *Torsion* $\sigma_1 = S$, $\sigma_2 = 0$, $\sigma_3 = -S$. $\frac{1}{2}\left[\Sigma(\sigma_1-\sigma_2)^2\right] = 3s^2$

$C_1 = 3^m S^{2m} A\left[2^n S^n + S^n\right] = 3^m\left[1+2^n\right] A\,S^{2m+n}$

$C_2 = 3^m S^{2m} A\left[-2^n S^n - S^n\right] = -3^m\left[1+2^n\right] A\,S^{2m+n}$

$C_3 = 3^m S^{2m} A\left[-S^n + S^n\right] = 0$

Octahedral stress $\sigma_{os} = {}^1/_3\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{\frac{1}{2}} = \sqrt{\frac{6}{3}}\,S$

Octahedral Creep Rate C_{os}

$$= {}^2/_3\left[\Sigma(C_1-C_2)^2\right]^{\frac{1}{2}} = \frac{2\sqrt{6}}{3}C_1$$

$$= 2\sqrt{6}\,3^{m-1}\left[1+2^n\right] A\,S^{2m+n}$$

For equal tension and torsion $s = \dfrac{t}{\sqrt{3}}$

and $C_{os} = \dfrac{2\sqrt{6}\,3^{m-1}\left[1+2^n\right]At^{2m+n}}{3^{m+n/2}} =$

$$2\sqrt{2}\,3^{-\frac{(n+1)}{2}}\left[1+2^n\right]At^{2m+n}$$

and $C_{os} = 2\sqrt{2}\,A\,t^{2m+n}$

For application of Hencky theory $C_{os} = C_{ot}$ and these functions can only be equal if $n = 1$ or 3. Therefore, in the original equation the second term in brackets must be either:

$$\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right]$$

or $\left[(\sigma_1-\sigma_2)^3-(\sigma_3-\sigma_1)^3\right]$

which in any case $= \left[\Sigma(\sigma_1-\sigma_2)^2\right]^2\left[(\sigma^1-\sigma^2)-(\sigma_3-\sigma_1)\right]$

Notation used in the Paper

The notation employed is as follows:

Applied tensile stress	t
Applied torsion stress	s
Major Principal Stress	σ_1
Minor Principal Stress	σ_2
Secondary Principal Stress	σ_3
Axial Creep Rate	C_a
Shear Creep Rate	C_c
Creep Rate in Direction of Major Principal Stress	C_1
Creep Rate in Direction of Minor Principal Stress	C_2
Creep Rate in Direction of Secondary Principal Stress	C_3
Octahedral Shear Stress	σ_o
Octahedral Shear Creep Rate	C_o

Acknowledgments

The work described above was carried out in the Engineering Division of the National Physical Laboratory as part of the programme of the Mechanical Engineering Research Board and this paper is published by permission of the Director of the National Physical Laboratory and the Director of Mechanical Engineering Research of the Department of Scientific and Industrial Research.

The author acknowledges the help of Miss Heathman of the Engineering Division who carried out many of the tests. He also acknowledges helpful advice from Mr. H. J. Tapsell of the same division.

For the assistance of readers familiar only with the metric system, or preferring to use this system, the factors for converting British to Metric units are given below:—

Length 1 in. = 25·40 mm.
Stress 1 ton/sq. in. = 157·43 Kg./sq. cm.

School of Gas Turbine Technology

THE above school, which is maintained by Power Jets (Research and Development) Ltd., was moved from its old location at Lutterworth to larger premises at Farnborough and the opening ceremony, on the 17th of this month, was performed by the Right Hon. G. R. Strauss, P.C., M.P., Minister of Supply, supported by Mr. David Hardman, M.P., Parliamentary Secretary to the Ministry of Education.

The syllabus has been completely revised and brought into line with current gas turbine developments, and the School, the only one of its kind in the world, now gives practical and theoretical instruction in the technicalities of all the uses of gas turbines. Students from all over the world have already attended the School, and many nationalities will be represented at the first international course to be held at Farnborough Place in November. The new address is: School of Gas Turbine Technology, Farnborough Place, Farnborough, Hampshire, to which enquiries should be sent.

Aluminium Alloy Castings

USERS and potential users of aluminium alloy castings will find a recent A.D.A. Information Bulletin (No. 17) invaluable, It has been specially prepared for those who obtain their castings from outside foundries for incorporation in their products. It contains notes on the characteristics of castings in general and those of aluminium castings in particular. The main casting processes, and, briefly, some special processes, are described in a manner designed to help the user appreciate the foundryman's point of view. This leads to the next two main sections: choice of casting method, and choice of alloy, where the importance is emphasised of co-operation between user and founder from the earliest stage. In notes on design this point is crystallised by illustrations showing the advantages gained by small modifications that ease foundry practice without materially affecting design.

Copies are available from The Aluminium Development Association, 33, Grosvenor Street, London, W.1., price 1s.

LABORATORY METHODS
MECHANICAL · CHEMICAL · PHYSICAL · METALLOGRAPHIC
INSTRUMENTS AND MATERIALS
OCTOBER, 1950 Vol. XLII No. 252

Chemical Analysis of Tin Bronzes

By J. W. Price, B.Sc., Ph.D., F.R.I.C.
Head of Analytical Section, Tin Research Institute.

The methods described in this article, for the determination of alloying elements and impurities in tin bronzes, have been used in the laboratories of the Tin Research Institute for many years. They have been selected to combine reasonable speed and a minimum of manipulation with an acceptable degree of accuracy. All employ purely chemical procedures so that special equipment is unnecessary for their execution.

THE term bronze has been used at one time or another to include many copper alloys. Without attempting to make a rigid definition, the methods of analysis described below are intended to apply to copper-base alloys containing at least 1% of tin, and possibly lead, zinc, phosphorus and nickel as additional alloying constituents. Other metals are considered as impurities, present to the extent of not more than 0·5%.

Although there are considerable advantages in the application of instrumental methods of analysis, particularly in the case of repetition analyses of the same type of alloy, it is considered that such methods, e.g., photometric, polarographic, spectrographic, require special techniques and equipment which are not always available in the works laboratory. The methods described here are therefore restricted to those which are purely chemical, although alternative techniques are briefly indicated where they are particularly suitable.

The methods described have been selected to combine reasonable speed and a minimum of manipulation with an acceptable degree of accuracy. They have been in use in the laboratories of the Tin Research Institute for many years.

Full details of standardisation of solutions, etc., have not been given, as they are well-known and available in standard text-books. The usual conventions as to acid strength, etc., are used, i.e., unless otherwise stated, all acids refer to the usual concentrated grades, and dilutions are given by volume, the amount of water being stated second.

COPPER

While in this class of material the amounts of the alloying constituents (Pb, Sn, Zn, P) are of major importance, the copper content is usually also determined if only as a check on the sum of the other metals present. The two methods in general use—the volumetric iodide-thiosulphate method and the gravimetric electrolytic method—are so well known that no details will be given here. Choice of method will depend on facilities available, and the type of alloy being analysed. For instance, copper and lead may be determined simultaneously by electrolysis in alloys containing up to 5% lead. It should, however, be borne in mind that a preliminary separation of the tin as metastannic acid, by solution of the sample in nitric acid, is necessary before determination of the copper by this method, unless the tin is complexed by HF. Further, in accurate work it is necessary to recover traces of occluded copper from the metastannic acid precipitate. The volumetric method has the advantage of being considerably the more rapid; when carefully carried out it gives results of acceptable accuracy.

TIN

The time-honoured method of weighing the ignited insoluble residue from nitric acid attack on the alloy, is still widely used. It is sufficiently accurate for routine control, in some cases, if the weight of tin oxide found is corrected for the impurities present.

Of these impurities phosphorus is usually the most important. It should also be remembered that the presence of more than about 0·25% of iron in the alloy will cause incomplete precipitation of the tin, while any antimony present will be included with the tin.

In general, however, a more accurate method of determination is to be preferred. Of the methods available the two most satisfactory are the volumetric iodine titration following nickel reduction, and the gravimetric tannin precipitation.

In both cases a preliminary separation from copper is necessary, and there are a number of procedures available. The most common is filtration of the tin as metastannic acid following nitric acid attack on the alloy. If dilute acid is used, solution of the sample will generally be rapid, but it will be necessary to evaporate to dryness to convert the tin to the insoluble metastannic acid before filtration. If concentrated acid is used, the tin is converted to the insoluble form immediately, but, particularly if the alloy has a high phosphorus content, dissolution of the alloy is slow and there is danger of considerable contamination of the tin precipitate. In both cases the solution must be kept hot during filtration to avoid loss of tin through re-solution of the metastannic acid. This method is most suitable for alloys of low tin content (~ 1%), particularly if high in lead, e.g., leaded bronzes. It is also useful for the separation of tin prior to the determination of another constituent e.g., zinc.

For alloys of higher tin content a simpler and more rapid separation is preferred. The alloy is completely dissolved in aqua regia, iron is added in the form of a solution of ferric chloride or nitrate and the solution is made alkaline with ammonia. The tin and iron hydroxides are then filtered on a rapid paper, the

precipitate dissolved in hydrochloric acid and the tin reduced to the stannous condition. (For alloys containing more than 5% lead, the bulk of the lead may be removed by precipitation with sulphuric acid before the hydroxide precipitation.)

Among other methods of separation may be mentioned the removal of copper as thiocyanate[1] or oxalate[2] and the distillation of tin as stannic bromide[3,4].

Volumetric Method

Procedure A (for alloys of low tin content—2% and under).—Dissolve a 5 g. sample in 25 ml. of nitric acid (2 : 1) and heat the solution to expel brown fumes. Dilute to 100 ml., with hot water, allow to settle on the hot-plate and filter through a Whatman No. 40 filter paper containing a little filter pulp. Keep the solution hot during the filtration and wash the precipitate free from copper with hot 1% nitric acid. Return the paper and precipitate to the original beaker and heat with 10 ml. of sulphuric acid and 15 ml. of nitric acid to destroy organic matter, and then evaporate to fumes. Cool, dilute with 10 ml. of water and again fume to remove all traces of nitric acid.

Cool, add 175 ml. of water and 75 ml. of hydrochloric acid and transfer to a 500 ml. Erlenmeyer flask. Add a nickel coil and close the flask with a stopper carrying a delivery tube dipping into a beaker of water. Boil the contents of the flask, with brisk evolution of gas from the nickel coil, for 40 minutes. Replace the beaker of water with a beaker of saturated sodium bicarbonate solution and remove the flask from the hot-plate. Cool to room temperature, add starch solution and titrate immediately with N/10 iodine or potassium iodate solution.

Procedure B (for alloys containing more than 2% tin).—Adjust the size of the sample to contain about 100 mg. of tin (e.g., for an alloy containing 10% tin take a 1 g. sample). Dissolve in aqua regia, and add 50 mg. of iron in the form of a solution of ferric chloride or nitrate. Make alkaline with ammonia, boil to coagulate and filter the tin and iron hydroxides on a rapid paper, washing free from copper with hot 1% ammonium chloride. (For alloys containing more than 5% of lead, the bulk of the lead may be removed by precipitation with sulphuric acid and filtration before making alkaline.) Dissolve the precipitate through the paper with hot hydrochloric acid (1 : 1) washing thoroughly with hot water. Transfer to a 500 ml. Erlenmeyer conical flask, adjust the volumes of acid and water to 75 and 175 ml. respectively, reduce with a nickel coil and titrate with iodine as described above.

Gravimetric Method[5]

Adjust the size of the sample to contain 50 to 100 mg. of tin, dissolve in aqua regia, add iron and precipitate with ammonia as described above (Procedure B). Dissolve the precipitate with 20 ml. of hot hydrochloric acid (1 : 1) containing 3 g. of ammonium oxalate, washing thoroughly with hot water. Add 1 g. of tannin, dilute to 250 ml., heat to boiling and precipitate the tin-tannin complex by addition of dilute ammonia. (The purple colour of the iron complex serves as an indicator—permanent discolouration of the precipitate must be avoided.) Filter on a rapid paper (Whatman 41) and wash twice with 1% ammonium nitrate. Return the precipitate to the original beaker, stir up with 50 ml. of 1% ammonium nitrate and filter through the same paper. Wash three times with 1% ammonium nitrate. Dry and ignite the precipitate in a silica crucible at 900°–1,000° C. and weigh as SnO_2.

NOTE.—In the presence of more than 10 mg. of lead a preliminary basic acetate separation is necessary.

In the presence of antimony, which is precipitated with the tin-tannin complex, a preliminary separation by boiling with nickel powder is necessary. (For details see the original paper.)

PHOSPHORUS

Precipitation of ammonium phosphomolybdate is the standard procedure for the separation of phosphorus in bronzes, the yellow precipitate usually being determined volumetrically. Well-established photometric methods are available based on the formation of molybdenum blue or the yellow complex with ammonium vanadate[6].

In referee analysis it is usual to separate the phosphorus from copper, tin, arsenic, etc., before precipitation[6]. In the direct method described below equally accurate results can usually be obtained with much saving of time.

Method.—Adjust the size of the sample up to a maximum of 5 g. to contain about 0·005 g. of phosphorus (e.g., for an alloy containing 0·5% phosphorus use a 1 g. sample). Dissolve in a mixture of 3 parts nitric acid, 1 part hydrochloric acid and 3 parts of water. (For a 5 g. sample use 70 ml.: for smaller samples, use 35 ml.) In the presence of more than 0·05% silicon add 3 ml. of HF and boil. Add 20 ml. of 5% permanganate, and heat to boiling. Add enough hydrochloric acid (5–10 ml.) to redissolve the precipitated manganese dioxide and boil to expel chlorine. Cool slightly and add 10 ml. of ammonia (1 : 1). Cool to 70° C. and add 35 ml. of ammonium molybdate solution. (In the presence of more than 0·01% arsenic cool to 25° C. before precipitating.) Stir or shake for 5 minutes and allow to stand for 30 minutes. Filter through a close paper (Whatman 42), wash out copper salts with 1% nitric acid and then wash out all acid with 1% ammonium nitrate. (Test washings with methyl orange.) Return the paper and precipitate to the original beaker, add 25 ml. of water and macerate the paper. Add a measured excess of N/10 sodium hydroxide, stirring to dissolve the yellow precipitate. Add phenolphthalein indicator and titrate the excess alkali with N/10 nitric acid.

1 ml. N/10 alkali ≡ 0·000135 g. P.

Ammonium molybdate solution: 65 g. ammonium molybdate, 225 g. ammonium nitrate, 50 ml. ammonia, diluted to 1 litre.

LEAD

Procedure A[7] *(for alloys containing from 1 to 5% lead.)*—Dissolve 1·5 g. in 15 ml. of nitric acid (1 : 1) and boil to expel brown fumes. Add 50 ml. of water and filter off the metastannic acid, washing thoroughly with hot 1% nitric acid. Make the filtrate alkaline with ammonia then add acetic acid until the solution contains 5% of the acid. Add 10 ml. of saturated potassium dichromate solution and boil for 10 minutes. Allow the precipitate of lead chromate to settle and filter on a rapid paper (Whatman 41). Wash with hot 5% acetic acid until the washings are colourless, and then with hot water. Return the paper and precipitate to the original beaker and add 25 ml. of a mixture of 100 ml. of phosphoric

acid and 180 ml. of sulphuric acid diluted to 1 litre. Then add 5 g. of ammonium chloride and 100 ml. of water. Add a measured excess of ferrous ammonium sulphate and titrate the excess with N/20 potassium dichromate using diphenylamine as indicator.

1 ml. N/20 dichromate = 0·003453 g. Pb.

(For lead present as an impurity i.e. <0·5%—a 3 g. sample should be used.)

Procedure B (for alloys containing more than 5% lead).—Dissolve 1 g. in nitric acid as above and filter off the tin. Add 10 ml. of sulphuric acid and evaporate to fumes. Cool, add 5 ml. of water and again evaporate to fumes. Cool, dilute to 150 ml., allow to stand for 1 hour and filter the lead sulphate on a tared Gooch or sintered glass crucible, washing the precipitate with cold water. Dry and ignite at 500° C.

$PbSO_4 \times 0{\cdot}6833 = Pb.$

ZINC

For the determination of zinc a preliminary separation of the metals of Group II is necessary, e.g., by precipitation as sulphides. Where these are being determined it is sometimes possible to use the same sample for the zinc determination. The following method[8] allows the separation of copper, tin and lead in one filtration.

For materials containing about 2% zinc use a 1 g. sample, for 5% zinc a 0·5 g. sample, and for small amounts as impurity a 2 g. sample.

Method.—Dissolve in 10 ml. of concentrated nitric acid, boil out brown fumes, add 3 ml. of concentrated sulphuric acid, dilute to 100 ml., make just alkaline with ammonia and then just acid with dilute sulphuric acid. Add 2 g. of potassium thiocyanate and 2 g. of sodium sulphite, heat nearly to boiling, and filter on a medium paper (Whatman 40), washing thoroughly with hot water. Cool and add 30 ml. of mercuric thiocyanate solution (27 g. mercuric chloride and 35 g. of ammonium thiocyanate per litre). Stir well and allow to stand for 3 hours (for zinc less than 0·5% stand overnight). Filter through a rapid paper (Whatman 41) and wash with 1% mercuric thiocyanate solution. Transfer the precipitate and paper to a 250 ml. bottle, add 35 ml. of hydrochloric acid, 10 ml. of water and 5 ml. of chloroform and titrate with standard iodate. Stopper the bottle and shake after each addition of iodate ; continue until the red colour in the chloroform disappears.

Potassium iodate solution : 19·65 g./litre (1 ml.= 0·001 g. Zn). For small amounts of zinc use a weaker solution of 3·929 g./litre (1 ml.=0·0002 g. Zn). Standardise against an alloy of known composition or against a known zinc solution.

NICKEL

Determination of nickel usually involves precipitation with dimethylglyoxime and either weighing of the complex or titration with cyanide after dissolving the complex in nitric acid. A preliminary separation of copper and tin is necessary, so the nickel determination may be combined with, for example, the determination of copper by electrolysis. Otherwise interference by copper may be prevented by reduction with hydroxylamine after removal of the tin in nitric acid. A photometric method is available, based on the colour produced by the action of iodine on the dimethylglyoxime complex in alkaline solution[6]. The following method gives a rapid separation of tin and copper together if these elements are not being determined.

Method.—Adjust the size of sample according to the nickel content : for 3–5% take 0·5 g. ; for 1–3%, 1 g. ; for 0·1–1%, 3 g. ; for less than 0·1%, 5 g.

Dissolve in the minimum of concentrated nitric acid and evaporate nearly to dryness. Dilute to 200 ml., add 25 ml. of 10% sodium hypophosphite for every 1g. of sample, and boil for 3 minutes. Add 1 g. of sodium sulphate dissolved in a little water and allow to cool. Filter through a medium paper (Whatman 40) containing pulp and wash with cold water. Add to the filtrate 10 ml. of 50% citric acid, neutralise with ammonia, and acidify with acetic acid. Heat to 70° C., add excess of 1% dimethylglyoxime in alcohol and 10 ml. of ammonia (1 : 1). Allow to cool, filter through a rapid paper (Whatman 41) and wash with hot water. Dissolve the precipitate in nitric acid, boil for 2 minutes and evaporate to low volume. Make just alkaline with ammonia and cool. Add 2 drops of a 10% solution of potassium iodide and titrate with standard cyanide until the white cloud disappears and one drop of the cyanide gives a clear solution.

Standard cyanide solution : 13·5 g. KCN, 5 g. NaOH and 0·5 g. $AgNO_3$ diluted to 1 litre and standardised against a solution of known nickel content as above (1 ml. = 0·003 g. Ni approx.).

IMPURITIES

Aluminium (0–0·1%)

The gravimetric phosphate method is usually satisfactory for this determination. If, however, an accurate figure is required for very small amounts (< 0·01%) a colorimetric method is necessary, following removal of interfering elements by electrolysis over a mercury cathode[9]. (For details of this procedure the original paper should be consulted.)

Method.—Dissolve 5 g. of sample in 40 ml. of nitric acid (1 : 1). Boil out fumes, dilute and filter off the tin, washing with hot 1% nitric acid. Add 10 ml. of sulphuric acid to the filtrate and evaporate to fumes. Cool, add 200 ml. of water, boil to dissolve salts, and filter off lead sulphate. Remove copper from the filtrate by electrolysis in the usual manner. Then make alkaline with ammonia and just acid with sulphuric acid. Pass H_2S into the solution and precipitate any traces of Pb, Sn, Cu. Filter and boil out H_2S from the filtrate. Add 10 g. of ammonium chloride and 1 g. of ammonium phosphate, neutralise with ammonia, make just acid with hydrochloric acid and add 10 drops excess. Bring to boiling, add 10 g. of sodium thiosulphate and 10 ml. of acetic acid, and boil for 15 minutes. Filter and wash thoroughly with hot water. Ignite strongly and weigh as $AlPO_4$.

$AlPO_4 \times 0{\cdot}2213 = Al.$

Antimony (0–0·5%)

In the presence of 5% tin or more, small amounts of antimony and arsenic are completely precipitated with the tin by nitric acid attack on the alloy.

Method.—Dissolve 5 g. in 50 ml. of nitric acid (1 : 1) adding pure tin, if necessary, to bring the tin content up to 5%. Boil out brown fumes, dilute with 150 ml. of water and allow to settle on the hot-plate. Filter through a close paper, keeping the solution hot during the filtration, and wash free from copper with hot nitric acid (1%). Transfer the paper and precipitate to a 400 ml. conical beaker, add 20 ml. of sulphuric acid and 10 ml. of nitric acid, and heat to fumes, adding more

nitric acid if necessary to obtain a clear solution. Cool, add 1 g. sodium thiosulphate crystals and fume strongly to redissolve sulphides and remove sulphur. Cool, add 100 ml. of water and 5 ml. of hydrochloric acid, heat to 80° C. and titrate with standard bromate N/20, using methyl orange as indicator.

1 ml. N/20 bromate = 0·003044 g. Sb.

In the presence of significant amounts of arsenic, deduction should be made of 1·6 parts of antimony for every 1 part of arsenic.

Arsenic (0–0·5%)

The standard method of separation of small amounts of arsenic in copper alloys is by distillation of the trichloride. An excellent alternative is the precipitation of the element by means of hypophosphite followed by titration with iodine[10]. Choice of method will again depend on personal preference and on facilities available. The distillation method is described below.

Method.—Place 5 g. sample in the flask of the standard distillation apparatus (preferably all-glass), add 30 g. of ferric chloride (cryst.), 15 g. potassium bromide and 200 ml. of hydrochloric acid (1 : 3). Have the end of the condenser dipping into a few ml. of water in the receiver, and distil off 150 ml. It is not necessary to cool the distillate. Heat the distillate to 80° C. and titrate with N/50 potassium bromate, using methyl orange as indicator. Deduct a predetermined blank.

1 ml. N/50 bromate = 0·00075 g. As.

A single distillation is sufficient to remove all the arsenic up to 0·3% and 95% between 0·3 and 0·5%. If the arsenic content is high and extreme accuracy is required, a further 50 ml. of hydrochloric acid (1 : 3) should be added to the flask after collection of 150 ml. and a further 50 ml. distilled. Arsenic is then titrated in the combined distillates of 200 ml.

Bismuth (0–0·1%)

Isolation of small percentages of bismuth involves a large sample and considerable manipulation; a direct colorimetric measurement on the solution after removal of copper and tin gives excellent results.

Method[11].—Dissolve 2 g. in 20 ml. of aqua regia (1 : 1) and boil out brown fumes. Cool, neutralise with ammonia, acidify with sulphuric acid (1 : 3) and add 10 ml. in excess. Add 12 g. of potassium iodide and a solution of 5 g. of sodium hypophosphite in 20 ml. of water. Allow to stand for 10–15 minutes to remove free iodine, leaving a white precipitate of cuprous iodide. Dilute to 200 ml. and filter off 100 ml. through a dry 11 cm. paper (Whatman 40) into a Nessler tube. For comparison make up a solution containing 5 ml. of sulphuric acid (1 : 3), 1 g. potassium iodide and 1 g. of hypophosphite, and add a standard bismuth solution (1 ml. = 0·0001 g. Bi) until, on diluting the comparison tube to 100 ml., the yellow colours match.

If preferred, the yellow colour may be extracted with a mixture of amyl alcohol and ethyl acetate and measured photometrically[12].

Iron (0–0·5%)

There are a number of satisfactory procedures available, and choice of method is a matter of personal preference. Colorimetric methods are much used, e.g., with phenanthroline, thioglycollic acid or thiocyanate. Two alternative methods of separation are given below, both of which are of general application.

Procedure A.—Dissolve 2 g. in the minimum amount of aqua regia, add 5 ml. of sulphuric acid (1 : 2) and evaporate to fuming. Cool, dilute to 250 ml. and saturate with H_2S. Warm to coagulate and filter off sulphides with suction, washing with H_2S solution acidified with sulphuric acid. Boil out all traces of H_2S from the filtrate, cool and oxidise by titration with N/50 permanganate. Add 10 ml. of 10% ammonium thiocyanate and titrate with N/50 titanous chloride until the red colour is discharged. (For routine purposes the iron content may often be calculated from the permanganate titration without performing the titanous chloride titration.)

Procedure B[6].—Dissolve 5 g. in 50 ml. of nitric acid (1 : 1) boil out brown fumes, settle and filter off the tin, washing with 1% nitric acid. Return the precipitate and paper to the original beaker, add 15 ml. of nitric acid and 10 ml. of perchloric acid. Heat to fuming, cool and add 10 ml. of hydrobromic acid. Evaporate to fumes to expel the tin, adding a further 10 ml. of hydrobromic acid if necessary to obtain a clear solution. Combine with the original filtrate and make alkaline with ammonia. (If the alloy contains more than 1–2% of lead the bulk of it should be removed by precipitation as sulphate and filtration before making alkaline.) Boil to coagulate and filter through a medium paper (Whatman 40) washing out all copper with hot water.

Dissolve the precipitate through the paper with 20 ml. of hot hydrochloric acid (1 : 1) into the original beaker and wash the paper with hot water. Heat to boiling and add a solution of stannous chloride (50 g./l.) drop by drop until the yellow colour is discharged, and then one drop in excess. Cool and add 10 ml. of a saturated solution of mercuric chloride, 10 ml. of phosphoric acid (1 : 3) and 2 drops of sodium diphenylamine sulphonate indicator (2 g./l.). Titrate with N/50 dichromate to a purple end point.

Manganese (0–0·1%)

Direct oxidation with persulphate and titration with arsenite can be used satisfactorily for amounts of manganese down to about 0·03%, using a 2 g. sample. For less than this amount the manganese should be precipitated as MnO_2 from a 5 g. sample by alkaline hypobromite, filtered, oxidised to permanganate and determined colorimetrically with standard permanganate solutions.

Method.—Dissolve 2 g. in 30 ml. of mixed acids (100 ml. H_2SO_4, 125 ml. of H_3PO_4, 250 ml. of HNO_3 per litre) and heat to expel brown fumes. Add 50 ml. of hot water, 10 ml. of 1% silver nitrate and 2 g. ammonium persulphate. Heat to boiling and boil for 1 minute. Cool to room temperature, add 50 ml. of water and titrate quickly with standard sodium arsenite (1 ml. = 0·0003 g. Mn). Standardise the arsenite by means of a standard alloy, dissolved and titrated as above.

Silicon (0–0·1%)

The gravimetric method is the most satisfactory procedure, following dehydration with either sulphuric or perchloric acid. A second evaporation in order to recover the last traces of silica is unnecessary with this class of material.

Method[6].—Dissolve 5 g. of sample in 10 ml. of hydrochloric acid and 20 ml. of nitric acid. Add 40 ml. of perchloric acid (60%) and 30 ml. of hydrobromic acid.

Evaporate on the hot-plate to fuming, cover with a watch glass, and heat strongly for 10 minutes. Cool, add 150 ml. of water and heat to dissolve all salts. Filter through a medium paper (Whatman 40) and wash well with hot 1% hydrochloric acid. Ignite the filter and precipitate in a platinum crucible, cool and weigh. Add a drop of sulphuric acid and 2 ml. of hydrofluoric acid and evaporate to dryness. Ignite, cool and re-weigh. The loss in weight represents SiO_2.

$$SiO_2 \times 0{\cdot}4673 = Si.$$

Sulphur (0–0·05%)

Sulphur is traditionally determined either gravimetrically as barium sulphate, following wet oxidation, or by combustion in oxygen to sulphur dioxide, followed by oxidation and determination of the sulphuric acid formed either volumetrically or gravimetrically. A simpler and more rapid method which gives equally acceptable results is the hydrobromic acid evolution method[13], exactly similar to the well-known method for sulphur in steel.

Method.—Place 5 g. of sample in the flask of an all-glass sulphur evolution apparatus and add 1 g. of stannous chloride. To 150 ml. of water in the absorption beaker add 10 ml. of ammoniacal zinc sulphate solution (100 g. of zinc sulphate dissolved in 500 ml. of water and 500 ml. of ammonia (Sp. gr. 0·880) added). Add 100 ml. of hydrobromic acid (Sp. gr. 1·49) through the tap funnel of the flask and warm gently to dissolve the sample. When solution is complete bring to the boil and boil for 3–5 minutes to expel all H_2S from the flask. Acidify the absorption solution with hydrochloric acid (1 : 1), dissolving the precipitated zinc sulphide, add 25 ml. excess and titrate immediately with standard iodate solution (N/50) using starch as indicator.

$$1 \text{ ml. N/50 Iodate} = 0{\cdot}00032 \text{ g. S.}$$

Oxygen (0·0002–0·02%)

The B.N.F.M.R.A. method[14] for the determination of oxygen by heating with hydrogen in a closed system to form water vapour, has been used successfully for bronzes, though special precautions may be necessary in the presence of considerable amounts of phosphorus or zinc.

In the absence of zinc a chemical method has been found to give good results. In a normal bronze any oxygen present will be combined with the tin in the form of SnO_2 in a crystalline form which is insoluble in dilute acid. The metallic portion of the sample may then be dissolved and the insoluble matter filtered and weighed.

Method.—Dissolve a sample of about 100 g., preferably in the form of a single piece of metal, in a 1,000 ml. beaker in a mixture of 300 ml. of water, 300 ml. of nitric acid and 100 ml. of hydrochloric acid. (It is necessary to take a large sample owing to the segregation of the tin oxide.) Warm gently to complete solution, dilute to 1 litre and allow to settle. Decant most of the clear liquid and filter the precipitate on a fine paper (Whatman 42) washing thoroughly with hot 5% hydrochloric acid. Ignite and weigh the residue as SnO_2 and calculate to oxygen.

$$SnO_2 \times 0{\cdot}21 = \text{Oxygen.}$$

This residue may be contaminated with silica, and for high accuracy it may be necessary to fuse with sodium hydroxide and determine tin in the usual way.

Acknowledgment

The author is indebted to the International Tin Research and Development Council for permission to publish this article.

REFERENCES.

1 "Standard Methods of Chemical Analysis," Scott and Furman, 1939.
2 Edwards, F. H., and Gailer, J. W., *Analyst*, 1944, **69**, 369; *Ib.* 1945, **70**, 365.
3 Lehmann, H. L., *Analyst*, 1945, **70**, 428.
4 Mogerman, W. D., *J. Research Nat. Bureau of Standards*, 1944, **33**, 307.
5 Holness, H., and Schoeller, W. R., *Analyst*, 1946, **71**, 70 and 217.
6 A.S.T.M. Methods of Chemical Analysis of Metals, 1946.
7 Fisk, P. M., and Pollak, F. F., *J. Chem. Soc.*, 1943, **1**, 41.
8 Hoffman, W., and Thackray, G. B., *Analyst*, 1941, **66**, 321.
9 Price, J. B., and Payne, S. T., *Analyst*, 1949, **74**, 641.
10 Evans, B. S., *Analyst*, 1929, **54**, 523.
11 Fitter, H. R., *Analyst*, 1938, **63**, 107.
12 Haddock, L. A., *Analyst*, 1934, **59**, 163.
13 Leysaht, H. *Z. anal. Chem.*, 1928, **75**, 169.
14 Baker, W. A., *Metallurgia*, 1949, **40** (238), p. 188.

Correspondence

The Argon Arc Melting Technique

The Editor, METALLURGIA.

Sir,

I was interested to read in your August 1950 issue the article by Dr. Geach and Mr. Summers-Smith dealing with an argon-atmosphere arc furnace of the type developed by Kroll. From the acknowledgments expressed in the article, I gathered that the design and operation of the furnace were largely based on information obtained from the Baillieu Laboratory in the University of Melbourne. This latter point was of especial interest to me because I was chiefly responsible for the establishment of the argon arc melting technique in Melbourne and it was I who furnished the information which Dr. Geach and Mr. Summers-Smith appear to have used. Here I should like to make it clear that in designing our own furnace, I drew very heavily from the drawing published in Kroll's original paper (Trans. Electrochem. Soc. vol 78 (1940), p. 35).

Some of your readers may be interested to learn of one or two recent applications of the furnace in our laboratory. By giving a little more than the usual attention to the vacuum technique and the gettering of the argon, Dr. A. D. McQuillan has been able to melt iodide-refined titanium and high-purity titanium-base alloys with scarcely any detectable contamination. Those familiar with the great reactivity of molten titanium will appreciate this achievement. Another of my associates, Mr. A. E. Jenkins, has been successful in using a trough-shaped copper hearth to produce elongated "ingots" of titanium and its alloys. The "ingots" are more convenient in most working operations than are the button-shaped pieces illustrated in the paper by Dr. Geach and Mr. Summers-Smith.

In conclusion, may I use your columns to express my own enthusiasm concerning the inert atmosphere arc melting method. It is now well over two years since I first found how useful the technique is, and I have been particularly interested to learn from recent issues of METALLURGIA that research laboratories in England are also adopting it.

Yours faithfully,

H. W. WORNER.

Commonwealth Scientific and Industrial Research Organization—Physical Metallurgy Section,
The Baillieu Laboratory, University of Melbourne,
N.3, Victoria, Australia.
October 10th, 1950.

The Electrolytic Polishing of Zirconium and its Application to a Study of the Effects of Abrasion Upon the Structure of the Metal

P. A. Jacquet *(Paris)*

The difficulties attendant on the preparation, by normal metallographic procedures, of etched specimens of zirconium suitable for microscopic examination, emphasize the importance of electrolytic methods of polishing. In this article, Dr. Jacquet deals briefly with the methods which have proved satisfactory and with their application to a study of the effect of abrasion on the structure of the metal.

ZIRCONIUM, as it is usually met with, is very hard: it is also a difficult metal to etch and is probably sensitive to cold work by abrasion. For these reasons electrolytic polishing of the metal should be of considerable interest in metallography, but no method of doing this has been noted in the literature. Very satisfactory results have now been obtained by means which are described in this article.

Two samples of zirconium were used, a small button made by melting technical powder of a purity "better than 99%" in an arc furnace under an atmosphere of argon, and a small piece of recrystallised zirconium strip of unknown origin.

Dilute Perchloric Acid Electrolyte

The most satisfactory procedure found was the use of a dilute perchloric acid electrolyte in an apparatus sold under the name "Disa-Electropol."[1] In this apparatus between 0·3 and 1 sq. cm. of specimen can be polished. The electrolyte, which has only recently been introduced[2], consists of 350 ml. of 95% ethyl alcohol, 100 ml. of perchloric acid (density 1·20) and 50 ml. of 2-butoxy-ethanol ("Butyl Cellosolve"). A specimen with an area of 0·3 sq. cm. which had been ground on No. 1 and No. 0 emery papers polished in 10 to 20 seconds, about 30 volts being used across the cell. The excellent quality of the micrographs obtained at several magnifications is illustrated by Figs. 1, 3, and 4. These show transverse sections of the bead of melted zirconium.

The structure of this material is clearly heterogeneous, consisting of a solid solution and of small insoluble constituents which often form a eutectic mass (Figs. 3 and 4). The solid solution is itself not uniform, as is shown by certain of the lines visible faintly in Fig. 4. The appearance suggests that the structure consists of dendrites of pure metal separated by areas containing impurities in solution and others precipitated in eutectic form. This is confirmed by examination of a specimen etched electrolytically as described later.

As zirconium has an hexagonal close-packed structure the grains should be distinguishable on a polished but unetched surface when this is examined by polarised light. This is exactly what is observed and Fig. 2 shows the same field as Fig. 1, photographed by polarised light. On comparing these photomicrographs it is interesting to notice that the grains differentiated by contrast (Fig. 2) are not always those defined by the films of insoluble matter which may lie within a crystal, (Fig. 1). Presumably the impurity outlines the original grains of body-centred cubic zirconium which form on freezing and transform to the hexagonal structure during cooling. Grain-growth during cooling, but while the metal is still hot, could also account for the phenomenon. In the absence of information about the nature of these impurities it is not possible to be more definite on this point.

It appears that the conditions existing in the

1 *Metal Industry*, **75**, (1949), p. 493.
2 Knuth-Winterfeldt, E., *Mikroskopie*, **5**, (1949) p. 184.

Fig. 1.—Melted zirconium. "Disa-Electropol" polish. × 400

Fig. 2.—The same field as shown in Fig. 1, but illuminated by polarised light. × 400

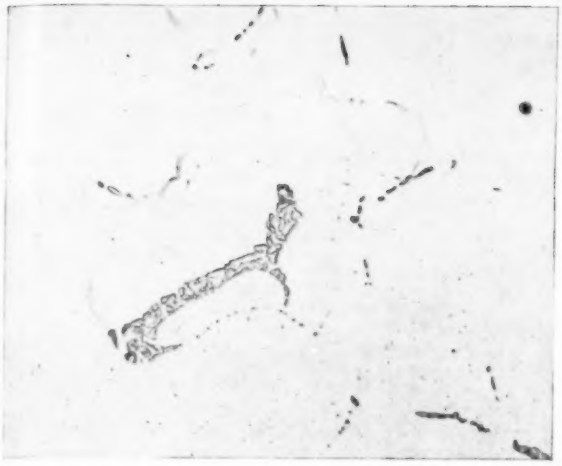


Fig. 3.—Melted zirconium. "Disa-Electropol" polish. × 1,300

Fig. 4.—Melted zirconium. "Disa-Electropol" polish. × 2,000

apparatus are important for successful polishing. Thus, using the same electrolyte in a simple cell does not give such good results as the commercial apparatus. Probably the temperature is the important factor and this is more easily controlled in the "Disa-Electropol" apparatus in which there is violent agitation of the electrolyte in contact with the surface of the specimen.

Diluted Acetic-Perchloric Electrolyte

Some success in polishing zirconium in a simple cell has been obtained using a diluted acetic-perchloric electrolyte. This bath has already been found suitable for polishing iron and steels[3], chromium,[3] uranium,[4*] and titanium[5]: it consists of 1,000 ml. of pure acetic acid and 50 ml. of perchloric acid of density 1·59. Because of the small concentration of perchloric acid there is no danger in using this bath, no matter what the temperature. Using a current density of 0·6 to 0·8 amps. per sq. cm. at 60 volts, with vigorous stirring, an excellent polish was obtained on specimens of pure zirconium strip. Examination by polarised light revealed very regular crystallisation in this material (Fig. 5).

With cast zirconium this solution gave much less satisfactory results. Although polishing did occur, in that grinding marks were rapidly eliminated, the surface was strongly etched. Under the microscope it was seen that only the areas between the dendrites were attacked and, as might be expected from the results obtained with the strip of pure metal, the dendrites of pure zirconium were well polished (Fig. 6). This acetic-perchloric bath is, therefore, most likely to be of interest for zirconium which is quite homogeneous, although since it makes interdendritic impurities so clear it may be of value in metallographic control of the quality of the metal. Conditions might be found which reduced the etching action of this electrolyte: no doubt very vigorous stirring would help.

3 Jacquet, P. A., *Comptes Rendus*, **227** (1948), 556; *Rev. Metallurgie*, **46** (1949), p. 214; *Sheet Metal Industries* (March 1949), p. 577.
4 Jacquet, P. A. and Caillat, R., *Comptes Rendus*, **228** (1949), p. 1224.
5 Sutcliffe, A. A., Forsyth, J. I. M. and Reynolds, J. A., *Metallurgia*, **41** (1950), p. 283.

* It may be of interest to record that uranium is polished very successfully by the procedure described above for zirconium.

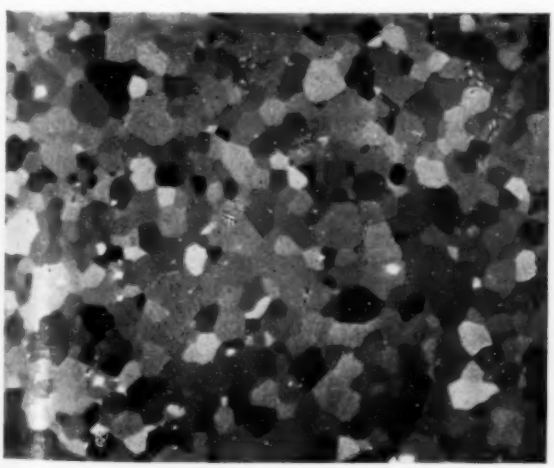


Fig. 5.—Annealed zirconium sheet. Polished in acetic-perchloric bath. Photographed by polarised light. × 400

Fig. 6.—Melted zirconium. Polished in the acetic-perchloric bath. The inter-dendritic structure is strongly etched. × 160

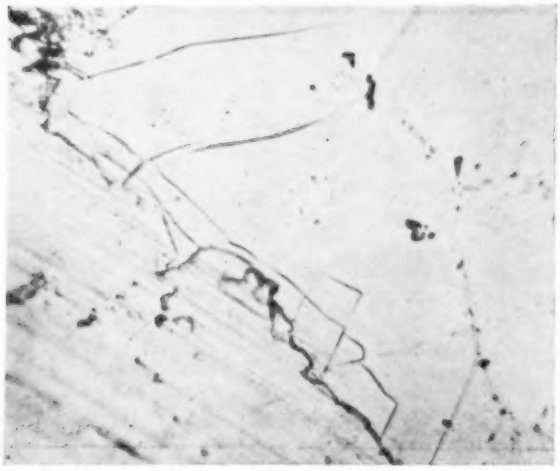


Fig. 7.—Structure along the edge of a scratch in the melted zirconium. "Disa-Electropol" polish. × 1,000

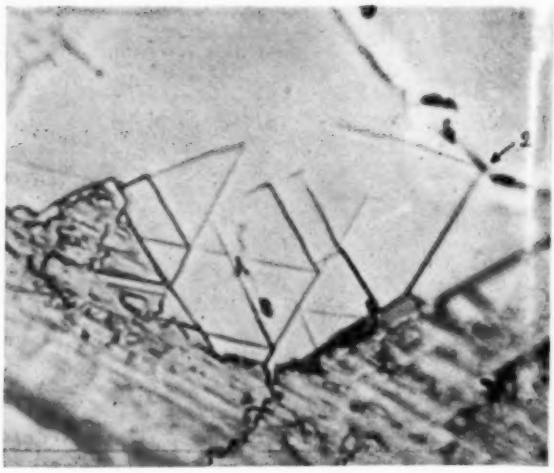


Fig. 8.—Another part of the same specimen as Fig. 7. × 2,000

Effect of Abrasion on Structure

Electrolytic polishing has made it possible to study in melted zirconium certain structural effects caused by abrasion. The grains of this material were roughly 0·05 to 0·5 mm. across. A scratch was drawn on a polished specimen using a hard steel point and sufficient load to trace a sharp groove. Beside such a scratch, slip lines appeared like those obtained in similar experiments on brass[6], copper or aluminium[7]. Some of the principal things observed are to be found in Figs. 7 and 8. The slip lines may be more or less curved whilst remaining clearly parallel. Other points of interest are :—(i) the abrupt alteration in direction of slip lines, revealing their change from one system of slip planes to another, a phenomenon ("cross-slip") which is well known in connection with the plastic deformation of single crystals of cubic metals ; (ii) the sudden cessation of slip in the interior of crystals ; (iii) the reflection of a slip line where it meets a row of inclusions which is either a grain boundary or a boundary between branches of the dendrite structure (this is marked with arrow "2" in Fig. 8) ; (iv) the presence of slip lines within the trace of a scratch (arrow "1" in Fig. 8).

Slip lines, which are the first traces of slip on certain specific crystallographic planes to be observed microscopically, are far less abundant in zirconium than those found under similar conditions in copper or aluminium. This difference is clearly due to the number of slip planes in an hexagonal structure being smaller than in a cubic one. Moreover, as its hardness shows, zirconium has only a small capacity for plastic deformation while cold. This technique of scratching electrolytically polished zirconium makes it easy to observe the progress of slip as the load is increased, and may perhaps make it possible to see the development of fissures between grains or of cleavages within them. Such a study should show readily how the capacity of a metal for plastic deformation depends upon its nature and purity.

When a surface which had been scratched was again polished electrolytically, signs of plastic deformation in the form of orientated striations were found at the sides of the scratch. These result from selective attack of material disturbed by the slip. Fig. 9 shows the specimen used for Figs. 7 and 8, after a very short repolishing in the acetic-perchloric bath. The severe inter-dendritic attack appearing in this micrograph was not observed if the first procedure described in this paper was used for the repolishing. It is yet possible, however, that, because of its etching action, the acetic-perchloric bath will prove to be the more useful for revealing the internal disturbances brought about by abrasion of a surface. It is noteworthy that such disturbances, which are well known in more readily deformable metals, are liable to mask true micrographic structure even in such a hard metal as the melted zirconium used for this work. In this connection, at least, electrolytic polishing of the metal is of interest.

The author wishes to thank Dr. G. A. Geach, Section Leader of the Physical Metallurgy Section of the Research Laboratory of Messrs. Associated Electrical Industries, Ltd., Aldermaston, for having supplied him with the melted zirconium used in the present work.

6 Jacquet, P. A., *Comptes Rendus*, **228** (1949), p. 1027.
7 Whitehead, J. R., *Research*, **2** (1949) 145 ; *Proc. Roy. Soc.*, **201A** (1950), p. 109.

Fig. 9.—The same specimen as shown in Fig. 7, repolished for 20 seconds in the acetic-perchloric bath. Cold-worked material occurs where the scratch had been. The inter-dendritic material is strongly etched but the solid solution is polished.

Some New Indicators in Various Titrimetric Processes

By A. J. Nutten, B.Sc, A.R.I.C.
Department of Chemistry, The University, Birmingham

Recent years have seen the development of many new indicators for titrimetric work. Following his consideration of new acid-base indicators of various types, the author discusses new indicators in the redox and iodometric classes.*

II.—REDOX INDICATORS

The literature on reduction-oxidation indicators (with an oxidation potential > 0·7 V) up to 1938 has been extensively reviewed by Whitehead and Wills,[32] while Kolthoff[33] has covered briefly the main developments in this field of analysis during the last five years. In the present section, details of most of the redox indicators mentioned by Kolthoff are given, while duplication of the former review has been reduced to a minimum. In addition, several new indicators, not listed in either of the above reviews, have been included.

2,2′-Dipyridyl Ferrous Complex

Orange (reduced)——→Colourless (oxidised)

Cagle and Smith[34] used the 2,2′-dipyridyl ferrous complex as indicator in the oxidimetric determination of iron by cerate after using the Jones reductor for reduction of the iron.

Indicator Solution : 1·65 g. of 2,2′-dipyridyl ferrous perchlorate dissolved in 1 litre of distilled water (an approximately saturated solution). 1 ml. per titration.

The indicator colour change (orange to almost colourless) is vivid and reproducible in 200–300 ml. of solution, and may be repeatedly reversed at the end-point by addition of excess ferrous ion or cerate ion, without decomposing the indicator compound.

Using the sulphato-cerate ion as oxidant, a solution of ferrous sulphate in sulphuric acid may be titrated without the use of phosphoric acid to decolorise the ferric ion formed by the oxidation. The indicator blank under given conditions is negligibly small.

1, 10–Phenanthroline Ferrous Complex

Red (reduced)——→Pale-Blue (oxidised)

The 1, 10–phenanthroline ferrous complex is red in colour and can be reversibly oxidised to a pale-blue compound. The complex has been successfully used by Smith and Richter[35] as a sensitive redox indicator in titrations with ceric ion.

Indicator Solution : 5·9465 g. 1,10–phenanthroline, 2·7802 g. ferrous sulphate heptahydrate, dissolved in distilled water to 1 litre. 1 drop per titration.

On oxidation, the transition E.M.F. (n–hydrogen electrode as reference) is 1·06 volts.

The ferrous complexes of 5–nitro–1,10–phenanthroline and 5–methyl–1,10–phenanthroline have been studied by the above workers, and found to be satisfactory as reversible redox indicators. Both compounds give the same colour change on oxidation as 1,10–phenanthroline, and their respective transition E.M.F.s are 1·25 v. and 1·02 v.

Due to their high oxidation potentials, the use of these indicators has been mainly restricted to titrations with the ceric ion.

* *Metallurgia*, **42**, 251, 216–219, September, 1950.

2, 2′ Dipyridyl Ruthenium Complex

Yellow (reduced)——→Colourless (oxidised)

The 2,2′–dipyridyl ruthenium nitrate complex is yellow in colour. The oxidised form of the complex is colourless, and this had led to its use as a redox indicator.[36]

Indicator Solution : 0·02 M solution of 2,2′–dipyridyl ruthenium nitrate. 2 drops/100 ml. solution.

The potential of the indicator is close to that of the ceric ion in sulphate solution and cannot thus be used successfully with this particular oxidant. However, ceric nitrate in nitric acid solution possesses a higher oxidation potential than the corresponding sulphate solution and, with this reagent, sharp end-points are obtained.

The molar oxidation potential of the indicator is 0·58 v. higher than that of the ferric-ferrous system measured against the quinhydrone reference electrode.

The corresponding potential on the hydrogen scale is 1·44 v. for ceric sulphate in 1 M sulphuric acid, and 1·61 v. for ceric nitrate in 1 M nitric acid.

The indicator furnishes an easily reversible reduction-oxidation system, and with its use, a solution of sodium oxalate in 2 M perchloric acid can be titrated directly at room temperature with 0·1 M ceric nitrate.

The 1,10–phenanthroline ruthenous ion has been investigated as a redox indicator, and its use for this purpose recommended.[37]

Diphenylamine Derivatives

Willard and Manolo[38] have investigated the indicator properties of various diphenylamine derivatives. In a series of experiments, they oxidised trivalent arsenic, antimony, and chromium, and hydrazine sulphate with excess of ferricyanide, added alkali, and back-titrated the excess ferricyanide with vanadyl sulphate. The end-point of the oxidation was detected with various diphenylamine derivatives, characteristics of which may be tabulated :

Indicator	Colour of Oxidised Form*	Drops of 0·02M Indicator per 50 ml. soln.
Diphenylamine–p–sulphonic acid†	Red	1
2–Carboxy–2′–methoxy–diphenylamine	Red	1
2–Carboxy–2′–methyl–diphenylamine	Red	2
2–Carboxy–diphenylamine	Red	2
2, 2′–Dicarboxy–diphenylamine	Blood-red	2
2–Carboxy–2′–bromo–diphenylamine	Red	2
2–Carboxy–3′–ethoxy–diphenylamine	Blood-Red	2

* Reduced from of indicator is colourless.
† Indicator first oxidised in acid solution.

In all cases the blank correction was negligibly small. The colour changes obtained are reversible and reasonably stable over the titration period. It is essential, however, that solutions containing the unstable oxidised forms are not allowed to stand for too long a period.

2-Carboxy-2′-methoxy diphenylamine is especially recommended for use with the ferricyanide–vanadyl sulphate system.

Direct titration of solutions of thiosulphate, thiocyanate, and trivalent antimony were performed with hypobromite in alkaline medium using diphenylamine–p–sulphonic acid and 2–amino diphenylamine sulphonic acid–4 as indicators. The first five indicators in the above table are recommended for use in alkaline solution.

N–Methyl diphenylamine–p–sulphonic acid[39] is claimed to be more stable towards oxidising agents than diphenylamine–p–sulphonic acid. Furthermore, it is soluble in water. The colour change is from colourless to purple-red in dilute acid solution.

The indicator may be used in the titration of ferrous iron with dichromate, permanganate or sulphato–ceric acid, a trace of oxidant in excess being sufficient to cause the indicator colour transition.

Kirsanov and Cherkassov[40] found that the introduction of the carboxyl radical into diphenylamine increased the oxidation potential of the indicator. The indicators studied were the 2,2′–, 2,3′– and 2,4′–diphenylamine dicarboxylic acids, and these are stated to be useful in solutions which are strongly acidic.

The end-point may be detected in oxidation–reduction reactions in solutions which are 16–20 N in sulphuric acid.

The use of diphenylamine sulphonic acid as an indicator in dichromate titrations was studied by Shcherbov[41] with respect to *p*H effects and stability. He recommends the use of the barium salt of the acid as being more satisfactory than diphenylamine.

Naphthidine

Colourless (reduced)——→Deep-Red (oxidised)

Naphthidine (4,4′–diamino–dinaphthyl–1,1′), the naphthalene analogue of benzidine, functions excellently as a redox indicator in titrations involving iron and chromium.[42] It gives a deep-red colour with a slight excess of dichromate, and the colour is strongly discharged by ferrous ion.

Indicator Solution : A 1% solution of naphthidine in concentrated sulphuric acid. 3 drops/250 ml. total volume.

Mercury salts do not interfere with the development and discharge of the colour, a fact of importance if stannous chloride is used to reduce the ferric iron as a preliminary to the dichromate titration.

The deep-red oxidation product is stable for 1½–2 minutes after the first drop of oxidising agent has been added and then gradually fades.

Cohen and Oesper[43] have described a simple preparation of naphthidine representing a great improvement on previous methods.

Toluylene Blue

Toluylene blue in dilute sulphuric acid solution has been used as an indicator[44] for the titration of ferrous ion with cerate, the colour change being reversible.

Sn^{+2}, Sn^{+4}, Hg^{+2}, HCl, and H_3PO_4 do not interfere, but the indicator cannot be used in presence of $HClO_4$. When boiled, the indicator loses hydrogen and becomes toluylene red, hence it is advisable to carry out the titration in the cold.

Brucine Sulphate

Colourless (reduced)——→Red (oxidised)

Miyagi[45] recommends brucine as an internal redox indicator in dichromate titrations of Sn^{+2} or Fe^{+2}.

Indicator Solution : 1 g. brucine sulphate dissolved in 100 ml. concentrated sulphuric acid. 20 drops per titration.

The indicator is claimed to be more satisfactory than diphenylamine. A trace of oxidising agent colours the indicator red, the reduced form being colourless.

Diphenylcarbazide

Violet——→Lavender——→Colourless

Crossley[46] describes a lengthy procedure for the titration of iron with dichromate using diphenylcarbazide as indicator.

Indicator Solution : 0·1 g. diphenylcarbazide dissolved in 30 ml. cold glacial acetic acid, and the solution diluted to 100 ml. with distilled water. 2 ml. per titration.

The titration procedure may be summarised: To a hydrochloric acid solution of Fe^{+2} add manganous sulphate solution, ferric sulphate solution and indicator. Titrate with dichromate, at a stipulated rate, and under given conditions, till the end point is reached, when the indicator is decolorised and the solution is coloured only by dissolved iron and chromium salts.

A blank for the indicator must be deducted.

Although the method is time-consuming, results are stated to be satisfactory.

Patent Blue V

Yellow (reduced)——→Orange-Red (oxidised)

Yoe and Boyd[47] report the use of Patent Blue V as either a redox or *p*H indicator. As a redox indicator it may be used in titrations with permanganate or cerate if chloride is absent. The indicator cannot be used with dichromate.

Indicator Solution : A 0·1% solution of Patent Blue V in distilled water. 3–5 drops per titration.

The indicator colour change is reversible.

(As a *p*H indicator, Patent Blue V gives colours varying from yellow, yellowish–green, bluish to pure blue with increasing *p*H. With the use of standards, the *p*H may be estimated to within 0·1 unit).

III.—IODOMETRIC INDICATORS

Amylose

I_2

Colourless——→Blue

The blue colour of the well-known 'starch-iodide' is caused by a complex of iodine with amylose, a constituent of starch. Using amylose as indicator, Ligett and Diehl[48] carried out titrations with 0·001 N solutions of iodine, and showed that when sufficient potassium iodide was present, the end-point was more sensitive than that obtained using soluble starch as indicator.

Indicator Solution : A 1% solution of amylose in distilled water. Only 2–3 drops of the indicator are used for each titration, whereas as much as 1 ml. of soluble starch indicator is generally required.

Methylene Blue

I_2

Colourless——→Blue

Iodine decolorises the blue colour of methylene blue, forming the hydriodide of tetraiodomethylene blue. Reducing agents such as Sn^{+2}, Hg^{+2}, SH^-, SO_3^{-2}, $S_2O_3^{-2}$, AsO_3^{-3} etc., restore the blue colour and this has led to the use of methylene blue as an iodometric indicator.[49]

It is claimed that methylene blue is as easy to use as starch, and is more reliable with dilute solutions (0·01 N or less).

Sodium Starch Glycollate

$$\text{Colourless} \xrightarrow{I_2} \text{Blue}$$

Sodium starch glycollate is preferred to starch as an iodometric indicator by Peat et alia.[50] It is well-known that starch indicator is insoluble in water and is unstable; furthermore, in dilute solutions end-point drifts are encountered. Sodium starch glycollate possesses none of these disadvantages, and can be added at the beginning of the titration as it forms a water-soluble iodine complex.

The authors give a detailed account of the preparation of the indicator. Bourne[51] has prepared sodium amylose glycollate from amylose, the preparation being similar to that of the starch compound. The preparation is troublesome, but the indicator possesses a greater sensitivity than its starch analogue.

IODATE INDICATORS

Amaranth (British Colour Index No. 184)

Brilliant Ponceau 5R. (British Colour Index No. 185)

Naphthol Blue Black (British Colour Index No. 246)

The colour of these substances is bleached by a trace of excess iodate. Smith and Wilcox[52] incorporated them as indicators in the well-known Andrews' iodate–iodine monochloride titrations[53], whereby an immiscible solvent is added to the solution, the end-point being indicated by the disappearance of the iodine colour from the solvent (excess of potassium iodate oxidising the iodine to colourless iodine monochloride in the presence of a large amount of hydrochloric acid).

These indicators represent a definite advance on the older method. Stoppering and shaking the titration flask is unnecessary, and the titration process is thus simplified.

The dyestuffs are stable in high concentrations of hydrochloric acid in the presence of small quantities of iodine or iodine monochloride; an immiscible solvent is not required with these indicators.

The authors give details for the titration of Sb^{+3}, Tl^{+}, Fe^{+2}, $S_2O_3^{-2}$, H_2O_2, HSO_3^{-}, CNS^{-}, NH_2NH_2, and $C_6H_5 \cdot NH \cdot NH_2$, for which results to within 0·5% of theory may be obtained.

Amaranth is the best indicator for most titrations. Unfortunately, these indicators are not available commercially in this country. However, a dye termed 'Technical Amaranth' is available (B.D.H. catalogue) and according to Belcher[54] this works equally well as the indicator grade Amaranth.

These indicators represent the latest advance in iodate titrations. The next step would be the development of reversible indicators for the titration.

Quite recently, Belcher has reported that p–ethoxychrysöidine works reversibly in this titration. However, the reversibility is limited; at the most, the titration can only be performed twice more since partial destruction of the indicator is most pronounced. Nevertheless, the indicator should prove useful in that overshooting of the end-point can be compensated by the addition of more As^{+3} or Sb^{+3}. This appears to be the first time a reversible indicator has been discovered for the titration.

REFERENCES

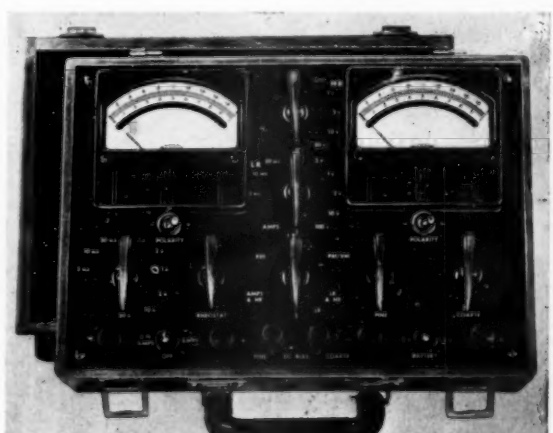
32 Whitehead, T. H., and Wills, C. C., *Chem. Rev.*, **29**, 69 (1941).
33 Kolthoff, I. M., *Anal. Chem.*, **21**, 103 (1949).
34 Cagle, F. W., and Smith, G. F., *Anal. Chem.*, **19**, 384 (1947).
35 Smith, G. F., and Richter, F. P., *Ind. Eng. Chem. (Anal. Ed.)*, **16**, 580 (1944).
36 Steigman, J., Birnbaum, N., and Edmonds, S. M., *Ind. Eng. Chem. (anal. Ed.)*, **14**, 30 (1942).
37 Dwyer, F. P., Humpoletz, J. E., and Nyholm, R. S., *J. Proc. Roy. Soc. (N.S. Wales)*, **80**, 212 (1946).
38 Willard, H. H. and Manolo, G. D., *Anal. Chem.*, **19**, 167 (1947).
39 Knop, J., and Kubelkova-Knopova, O., *Z. anal. Chem.*, **122** 183 (1941).
40 Kirsanov, A. V., and Cherkassov, V. P., *Bull. soc. chim.* (5), **3**, 2037 (1936).
41 Shcherbov, D. P., *Zavodskaya Lab.*, **14**, 794 (1948).
42 Straka, L. E., and Oesper, R. E., *Ind. Eng. Chem. (Anal. Ed.)*, **6**, 405 (1934).
43 Cohen, S., and Oesper, R. E., *Ind. Eng. Chem. (Anal. Ed.)*, **8**, 306 (1936).
44 Bollini, L. S. V. de, *Anales farm. bioquim (Buenos Aires)*, **18**, 115 (1947).
45 Miyagi, S., *J. Soc. Chem. Ind. Japan*, **38**, 146 (1933).
46 Crossley, H. E., *Analyst*, **61**, 164 (1936).
47 Yoe, J. H., and Boyd, G. R., *Ind. Eng. Chem. (Anal. Ed.)*, **11**, 492 (1939).
48 Ligett, L. M., and Diehl, H., *Anachem. News.*, **6**, 9 (1946).
49 Gautier, J. A., *Ann. pharm. franc.*, **6**, 171 (1948).
50 Peat, S., Bourne, E. J., and Thrower, R. D., *Nature*, **159**, 810 (1947).
51 Bourne, E. J. (private communication).
52 Smith, G. F., and Wilcox, C. S., *Ind. Eng. Chem. (Anal. Ed.)*, **14**, 49 (1942).
53 Andrews, L. W., *J. Am. Chem. Soc.*, **25**, 756 (1903).
54 Belcher, R. (private communication).

Instrument Developments

Electrolysis, Corrosion and Cathodic Protection Tester

WITH the new model, B-3, of the Miller Multi-Combination Meter, practically all measurements encountered in electrolysis and corrosion investigations and cathodic-protection testing in the field and laboratory can be made. By the use of a circuit selector switch, the two high-sensitivity D.C. instruments can be connected with a variety of measuring circuits for measurement of potentials, current, resistance and soil resistivity. Internal batteries with coarse and fine controls can be used to supply and control current for test purposes. Voltmeters, or voltmeter and ammeter can be used separately or simultaneously. Polarity reversing switches are provided for both current and potential measurements.

Unusually wide current and potential ranges and a number of measuring circuits are provided, as follows: 1,000 ohm/volt voltmeter with ten ranges from 2 mv. to 100 volts; 62,500 ohm/volt voltmeter with six ranges from 0·1 to 20 volts; potentiometer-voltmeter with six ranges from 2 mv. to 3 volts; D.C. biasing potential in series with high-resistance voltmeter to "back-to-zero" residual earth, pipe or electrode potentials to permit direct-readings of "change-in-potentials" up to 20 volts; ammeter with nine ranges from 2 ma. to 20



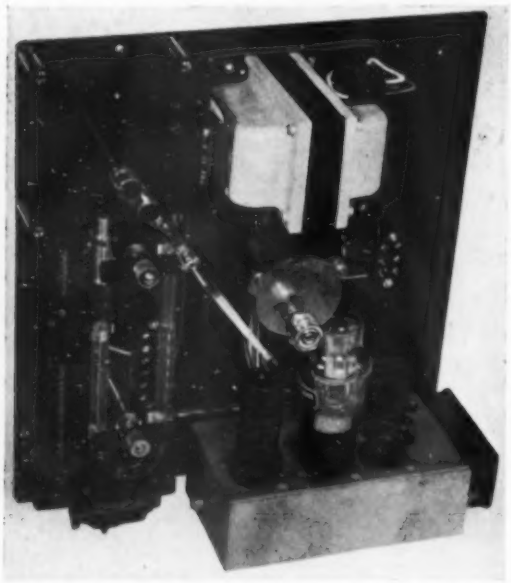
amp., low internal resistance, built-in current switch and current control rheostats ; zero-resistance type ammeter covering ranges up to 5 amp. A circuit is included for measuring resistance of leads, bonds, shunts, flanges, etc., and for measuring the resisting of soil to any depth by the four-electrode method, or a sample of soil or water in a soil box.

The instrument weighs 13 lb. and is mounted in a sturdy case. While high-sensitivity instruments, of an accuracy of 1%, are used, they are sufficiently rugged for the rough handling these meters receive in field work under extreme climatic conditions.

M. C. Miller, 1142, Emerson Avenue, West Inglewood, New Jersey, U.S.A.

Recording Manometer

MEASUREMENTS utilising differential pressures are commonplace in many industries, and one of the simplest methods of making such measurements is by means of a manometer. Fielden (Electronics) Ltd., have recently introduced a Manograph, a recording manometer, whereby pressure records may be obtained on a circular chart. This instrument is available in three forms : (*a*) for differential pressures up to 8 in. Hg., at low static pressures ; (*b*) for similar differentials at static pressures up to 400 lb./sq.in. ; and (*c*) for differential pressures as low as 2 mm. Hg. at low static pressures.



View of the internal arrangement of the instrument.

In the first two forms the liquid may be mercury, water or any other conducting liquid suitable for the differential pressures to be recorded. The manometer consists of a standard glass U tube in form (*a*), whilst in form (*b*) the liquid is contained in a piece of gauge glass tubing, glanded into a suitable welded steel structure. A small metal ring is placed round one leg of the manometer and is moved up and down by a lead screw turned by a servo-motor. A similar ring, placed lower down the manometer where liquid is always present, serves to earth the manometer liquid. The upper ring is maintained in a constant position, relative to the meniscus of the liquid, by an electronic capacity-sensitive device which operates the servo-motor. The movement of the ring is transferred to the pen mechanism, which records the pressure changes on the chart.

The arrangement in form (*c*), for differential pressures below $\frac{1}{2}$ in. W.G., is slightly different. The liquid, water or any low density liquid, is contained in comparatively wide bore tubes (connected at the bottom), one of which contains a light metal float which is kept away from the sides of the tube by fine ligaments. A flat electrode is mounted directly above the float and about 0·005 in. away from it. If the float rises or falls, the capacity of the condenser between float and electrode is altered, and the electronic circuit drives a plunger, in the other limb of the manometer, into and out of the liquid, so as to restore the float to its original position. The movement of the plunger, which is proportional to the change in pressure, is transferred to the pen mechanism.

The manograph is housed in a cast-aluminium splash-proof case, suitable for wall mounting, and is operated from the normal 230 V. 50 cycle A.C. mains.

Fielden (Electronics) Ltd., Paston Road, Wythenshawe, Manchester.

Instrument Sales and Service

HONEYWELL-BROWN, LTD., announce the recent opening of a Sales and Service office associated with their Scottish Works at Blantyre. The purpose of this office is to provide Scottish industry with readily available assistance on the technical application and maintenance of the Brown ElectroniK Potentiometer Pyrometer and Protectoglos being produced at those works. MR. P. R. PRIOR, who has had several years experience with the firm, on both sales and service, is in charge of the office. Correspondence for his attention should be addressed to him at Honeywell-Brown, Ltd., Block 4, Scottish Industrial Estates, Blantyre, Lanarkshire.

Standardised Spectrographic Materials

THE increasing application of the spectrograph in academic research, in industrial research and in production control has brought about an increased demand for standardised substances in recent years. Johnson, Matthey & Co., Ltd., have issued a revised edition of their publication No. 1760 "Standardised Substances for Spectrography, Chemical Analysis and Research," which describes the high purity materials marketed by the company. Full details of the metals and compounds representing sixty-eight elements and the forms in which they are available make the booklet a complete reference for users of standardised substances.

The Development and Application of Fourier Methods in Crystal Structure Analysis

THE X-Ray Analysis Group of the Institute of Physics is holding an autumn conference in the lecture hall of the Royal Society of Tropical Medicine and Hygiene, 26, Portland Place, London, W.1., November 16 and 17 next, at which the above subject will be discussed. The afternoon of November 16 will be concerned with the basic theory and the following morning the handling of the arithmatical problem will be discussed. An evening discourse on "Automatic Calculating Machines" will be given by Professor D. R. Hartree, F.R.S., on November 16th